I²E² 21Ulm

2nd Symposium on

# International Innovation, Engineering & Entrepreneurship

2021 Ulm

**IIEE** is presented by

Edited by

Robert Watty, Technische Hochschule Ulm

Hay Geradets, Fontys Eindhoven

Maximilian Lackner, MBA, Technikum Wien

Ignasi Florensa Ferrando, EUSS Barcelona

Leandro Di Domenico, ECAM Strasbourg

**Ulm, Germany, January 2021**

## Contents

Preface ........ 4
Innovation the drone light show industry ........ 5
Storage of electric energy in houses ........ 13
Different Food Packaging Concept – Innovation Engineering ........ 19
Reinforcing a FDM 3D print in the Z-direction ........ 27
Smart Mobility for Cities: Autonomous E-Scooter ........ 43
Devices to help companies execute corona policies ........ 51
Dynamic microplastic filter ........ 57
Self-Cooling Drinking System ........ 63
Innovation of the patient lifting crane hinge ........ 71
Solar Water Treatment ........ 79
BullsAi Gym Tracker ........ 85
Autonomous UV-C Disinfection Robot: Light Source ........ 96

## Make everything as simple as possible, but not simpler.

(Albert Einstein, born in Ulm 1879)

Our global world is complex and constantly changing, not only in pandemic times. This requires to carefully watch changes, to analyse and evaluate them, to ask the right questions and to give the right answers – still as simple as possible even if problems seem to be difficult.

Product development is an important source of our current prosperity and of our ability to preserve a healthy, sustainable and livable world in the future in Europe and all over the world. Actual and future markets in a globalized world are challenging companies in all fields of technology in developing their portfolio fastly.
Therefore innovations (= new and economically successful products) are a prerequisite for enterprises in order to be successful and competitive under these conditions. Furthermore most products require the interdisciplinary combination of e.g. mechanical, electronical and software components. Companies not only have to know their own area of expertise but also to be able to adopt quickly to a changing environment, open up new markets as intrapreneurs (= persons working within the company having entrepreneurial capabilities) and possibly developing lead innovations worldwide.

These tasks challenge the Innovative, Interdisciplinary, International, Intrapreneurial and Interpersonal (= i5) skills of engineers and universities of applied sciences have to be able to educate especially engineers to fulfil these requirements. Engineers also have to be able to command the entire chain from the first idea up to the product in the market. This chain includes product development, production and marketing.

The pioneering idea of an International Innovation Engineering Project ($I^2E^2$) was launched by my dear friend and colleague Hay Geraedts at Fontys in Eindhoven to teach students how to do this. The results of our second international cooperation with universities, colleagues and students from Barcelona, Eindhoven, Strasbourg, Vienna and Ulm are presented in our final symposium and described in these proceedings. They demonstrate the ability of our students, to successfully discover, attack and solve complex problems.

Thanks to all of you who supported to make this “simply possible”, especially to Geert-Jan Evers, Peter van Alem, Kennedy Aduda, Bert Huis in't Veld, Olaf van Buul, Maarten Haasnoot, Mohammed Samsam, Chris Lee, Ton Gielen, Jeedella Jeedella, Harold Benten and Abigail Albuquerque de Souza Daneluz from Fontys Eindhoven and Ralf Otte from THU

Ulm, 11.01.2021

Robert Watty. THU Ulm

# Innovation the drone light show industry

Jimmy Kusters, Diede Beijers, Ties Absil, Sacid Akinci, Floris van Rooij,
Niels van den Bos, Maud Oosterveld

Fontys University of Applied Sciences

Electrical Engineering, Mechanical Engineering, Applied Mathematics

Eindhoven, Netherlands

**Abstract:** Drone shows are expensive. They require a lot of prework before the show is ready to deploy. The time it takes to develop a show and to set it up makes the show expensive. Next to the development taking much time. The preparations before the show can really start requires also a lot of time. Because drones are not aware of the other drones in the sky. They have to be placed correctly so the drone knows where it is. Making a system that is able to track the drones will eliminate the preparation time immediate. Drones can start where ever they are placed and the system will figure it out and 'plays' the show and controls the drones accordingly. A path finding algorithm takes the coordinates determined by the localization system and returns the commands which are send to the drone to execute.

**Keywords:** Drone-show, Light-show, Entertainment, fireworks, Innovation

## 1. Problem description

Drone shows need a lot of preparation. Due to all the preparations a show can easily cost €20.000,- or even more. Composing the show and communicating with the client to make it perfect for the event will be the most expensive part. Setting up the show requires an operated who will place the drones on a grid of ±3m x 3m. This is done manually. So it is imaginable that if a drone show exist of 1000 drones or more that placing time is time consuming. And after the show they have to be picked up again.

Automating this process by developing a tracking system will cut this time. Which makes it possible to reduce the cost of a show. As less operators have to work less time this will be a large reduction in price. The benefits of being cheaper makes the service more attractive to costumers as competitors.

## 1. The system

A camera is placed in the ground facing upwards. The camera needs track the drones. As drone shows are at night most of the times, the drones led will only be visible. As this is a single point the camera can't detect the direction of the drone. For this reason, an odd number of IR LEDs will be placed on the bottom of the drone.

Infrared is chosen as this is not visible for humans so the camera can perform tracking with light without disturbing the show. Individual drones can be identify to loop though all drones and let them blink their LEDs. So only one drone will identify itself at a time.
The computer will receive the images of the camera and will perform some algorithms to track the drones. The view of the camera can be seen as the X and Y axis of the drones. So the coordinate of each drone can be measured. The third dimension will be measured by the drone itself. The drone measures its height and sends it back to the computer. Now the computer has XYZ coordinates of each drone.
Those coordinates will be fed in the path finding algorithm which will return the controls for the drone. The computer will send those controls to the drone and will check in the next iteration whether the drone is behaving correctly or not.

The first version of this idea also uses GPS and the camera would correct the GPS coordinates. As this adds an extra layer of difficulty and it can work without the decision is made to change the initial idea to a simpler and works the same.

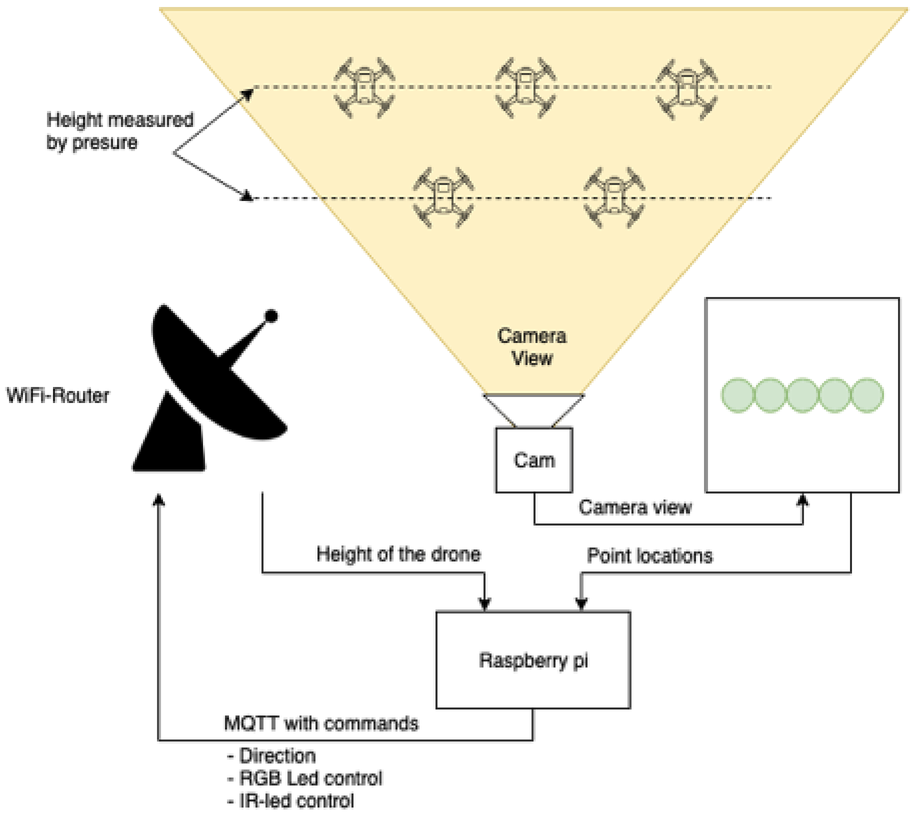



*Figure 1: Total system overview*

## 2.1 The drone

A four-rotor helicopter is the most stable option for a drone. It is mechanically simple and very efficient. Because of the four-rotor configuration the drone can roll, pitch and yaw very quickly and easy. This means that the self-balancing system is relatively easy. The onboard sensors output the three-dimensional orientation of the drone, the microcontroller will react fast and the motors will correct these angles to make the drone stable again. [5]

A quadcopter must consist of the following essential parts (figure 2):

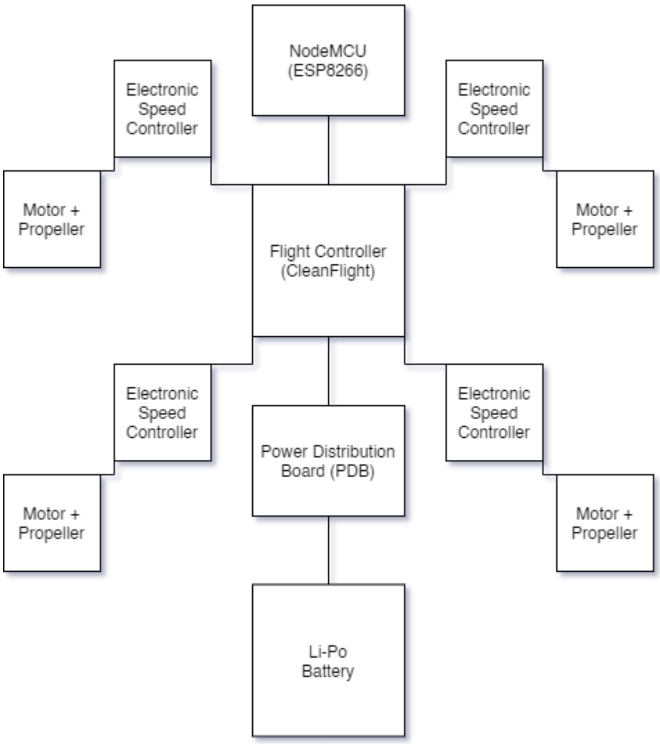



*Figure 2: Drone block diagram*

### 2.1.1 Rechargeable battery

The drones will need a rechargeable battery with a high discharge rate. A LiPo battery is the best option as power-source because these batteries have a high energy density and high discharge rate, this is important for the high current draw by the motors. The battery is the heaviest component of the quadcopter, a bigger battery doesn't mean it will fly longer.

### 2.1.2 Motors with propellers

Brushless motors are the most used on quadcopters. An efficient combination of propeller and motor is very important because the motors are the main drain of battery power. Maximum amp draw is also critical so that the ESC's are rated to withstand this amperage.

### 2.1.3 Electronic Speed Controller

An electronic speed controller is a device that receives signals from the flight controller and translates those signals into phased electrical signals to set the speed of a brushless motor. The flight controller and ESC's must be running the same ESC protocol, and the current rating must be higher than the amperage drawn by the combination of chosen motors and props.

### 2.1.4 Flight Controller (FC)

A flight controller (FC) is the brain of the drone. It is a circuit board with a range of sensors that detect movement of the drone, as well as user commands from wireless data signals. Using the sensor data, it then controls the speed of the motors to make stabilize the drone.

Existing FC's have sensors such as gyroscopes and accelerometer and several other insignificant but useful sensors such as barometer (altitude) and compass. The FC is also a hub for other peripherals, such as GPS, Sonar sensor etc. This differs per existing model.

The functions of the flight controller's do not end there. One of the major functions of a flight controller includes receiving and processing the input signals from the receiver and executing appropriate commands given by the software system.

#### 2.1.5 Electronic Speed Controller (PDB)

The PDB distributes power to the components at the required voltages. All-in-One (AIO) is a common term used for components that can fulfill more than one function. An AIO FC has in-built PDB and will have large pads for the heavy gauge wire for input voltage directly from your Li-Po Battery.

AIO FC's don't have radio receivers and ESC's for the motors. Although there are stacked FC's, which most of the time means that the FC comes with an PCB on top of it. Most of the time this extra PCB is a 4-in1 ESC, which are often designed as part of a stack for use with a specific FC, usually a 4-in-1 ESC acts as the PDB. The reason to go this route is to minimize the weight.

#### 2.1.6 Data receiving processing

The algorithm decides the path. The path decides the flight controls. The Flight Controls are: Throttle, Yaw, Pitch and Roll. Normally these are sent by a wireless Remote Controller to a receiver (2.6Ghz 6-channels). This receiver communicates these signals to the flight controller using Pulse Width Modulation (PWM). These signals can be imitated by a NodeMCU for example. Serial communication can also be used because of the Cleanflight firmware on the Flight Controller. This way the Flight Controller does not need any configuration. The NodeMCU also controls the IR- and RGB-led(s), to make the drone-show possible.

### 2.2 The tracking system

The tracking system consist a small computer with a camera attached to it. The camera is modified so it only receives infrared light. This reduces the computation required to find the infrared-lights. On every drone there are 3 IR-leds mounted facing down. The system captures an images and processes it. First it determines the triangles that resemble the drones flying in the sky. The system should detect as many triangles as drones. The reason each drone has more than one led is so the system is able to derive a direction the drone is facing

Now the triangles are found the system determines the middle of those triangles. Assuming that every pixel in the image is a point on a XY-graph. The system will convert the location of the pixel that is the middle of the triangle to a coordinate. Those coordinates will only contain the XY position of the drone. The Z-value is send by the drone to the system. The drones measure their height with their barometric-pressure-sensor.

After combining the XY coordinates with the Z coordinate received by the drone. The coordinates are fed to the pathfinding algorithm.

### 2.3 The pathfinding algorithm

The pathfinding algorithm is divided into steps. The first step is assigning all the targets to drones. Because to calculate a good path it must be known where each drone must end. The purpose of this part of the algorithm is to assign each drone a target, so that all the targets can be achieved as quickly as possible. In other words, this algorithm must minimize the largest distance between drone and target. It prioritizes that drones far away from a target will reach a target faster than drones close by. However, this makes that drones that are close to a target may not get the closest target.

The second step in the pathfinding algorithm is calculating the path. When calculating a path there are two priorities. The first priority is that drones may never collide and the second is that the drones must reach their target. The flowchart, below, visualize the steps and choices made in the algorithm. Form the moment that the real-time information is collected, using the tracking system, to the moment that the instruction are sent back to the drones.

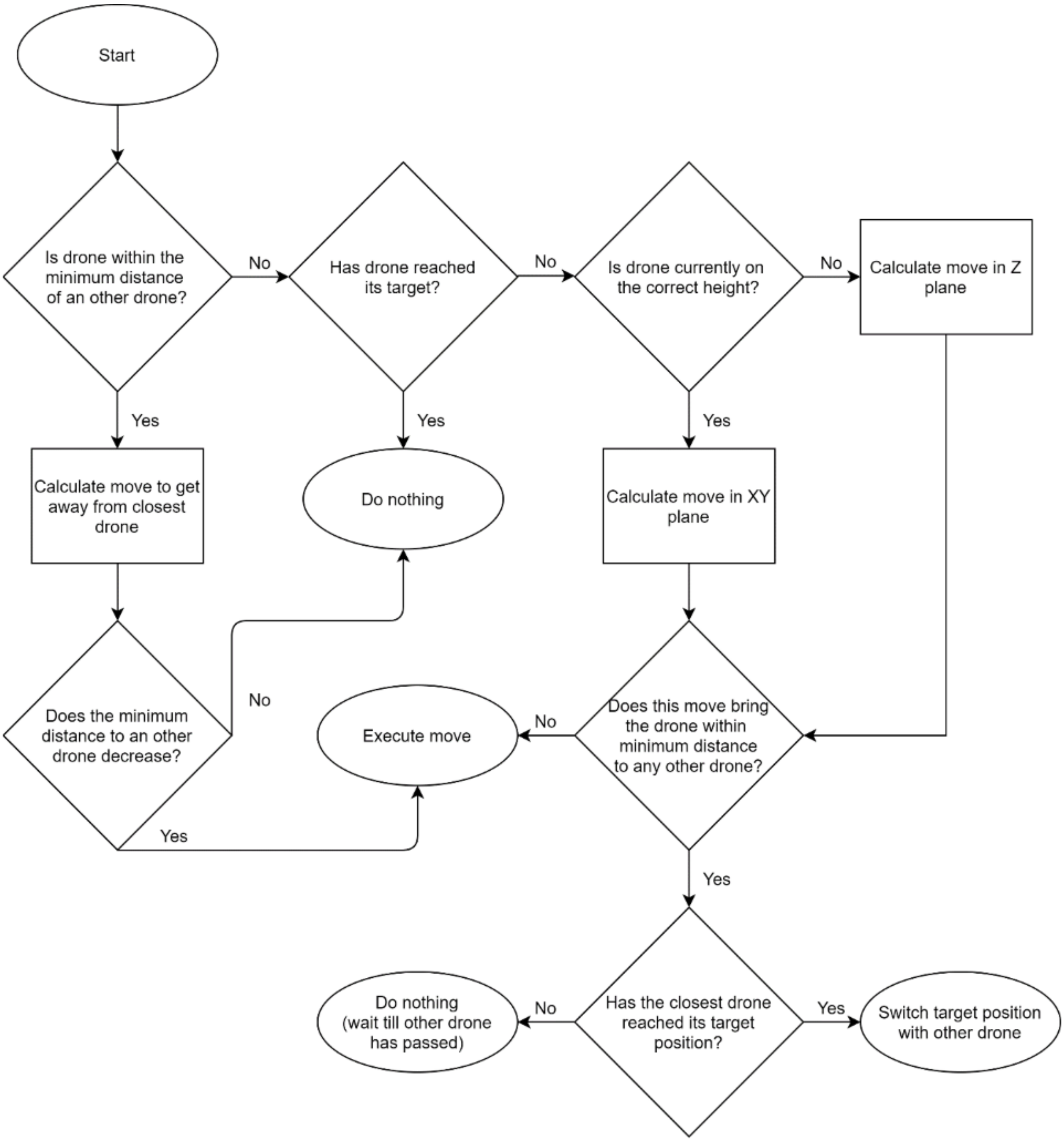



*Figure 3: Block diagram path finding algorithm*

The last step is sending the instructions to the drone. After this new information can be received and the algorithm can be called again.

### 2.4 Drone design

The design of the drone is determined by a number of demands:

- Relatively cheap to produce:
  As the drone is made for the general public (replacing fireworks) the drones price should be kept reasonably low.
- Stiffness/weight ratio:
  The frame should be sufficiently stiff to ensure it doesn't bow due to forces (wind, motor, weight), as weight is an important factor to the stiffness and also the flight time of the drone. The weight should be kept as low as possible in order to realize the wanted flight time.
- Emit a light source towards the public:
  The primary function of the drone is providing light towards the public, with the use of a light. Put this light in an array of drones and a lightshow is created. With the use of reflectors/dome the LED-light is dispersed into the sky, making it better visible for the public.

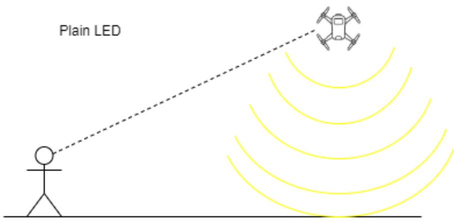



*Figure 4: Led emission without diffuser*

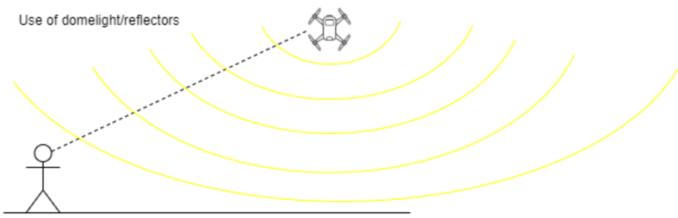



*Figure 5: Led emission without diffuser*

Because of ease of programmability and proper balance, the use of 4 rotors is chosen making it a quadcopter. To accompany a swift and efficient prototyping phase, certain design elements are of great importance. Parts should be easily changed and adapted to new design cues, meaning the parts need to be easily accessible (both bought and made), 3D-printing is an excellent candidate for this.
The physical design of the drone is led by the maximum propellor size, which the motor is able to power. This determines the minimum span width of the tubes, which is 250 [mm]. The motor mounting system is 16x16 [mm], these are the set dimensions of the drone.

Therefore a first concept of the drone has been designed.

#### 2.4.1 Prototype V1

The motor mounts, middle bracket and the landing gear are all 3D-printed out of PLA . The tubes connecting the parts together are made out of carbon, because carbon has a very high stiffness/strength to weight ratio making it an excellent candidate for the tubes. The choice was made to mount the battery and the light on the bottom of drone, this way the center of mass is lower (making it more stable) and the light can be observed better by the public. Other electrical components are mounted on top.

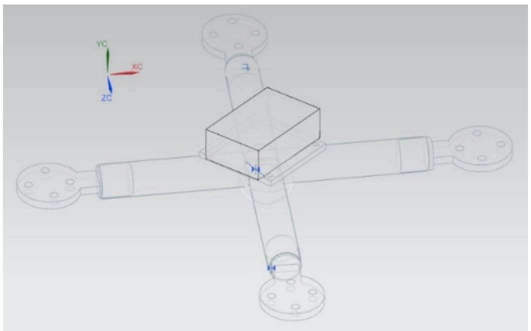


*Figure 6: Prototype V1*

Because of a ordering/production difficulty certain parts of the V1 prototype couldn't be produced. Therefore a second version of the prototype was created. This new design focuses it's ease of prodcution.

### 2.4.2 Prototype V2

3D-printing is used to print the full frame out of PLA. The battery and PCB are located in the upper half of the sphere. The bottom half of the sphere lights up and changes color during airtime. The bigger dome acts as an reflector making it easier for bystanders to see the drone show from a larger distance.

Besides these changes the drone design is the same as V1.

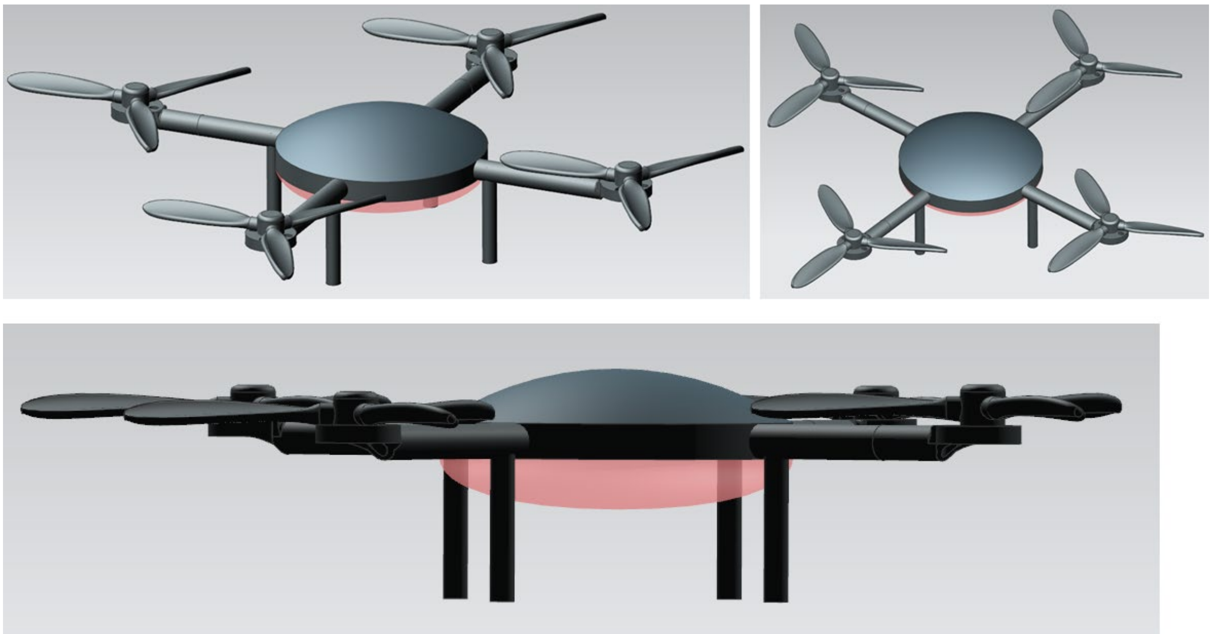


*Figure 6: Prototype V2*

## 2. Conclusion

After research and a small amount of testing, the drone-innovation-group found out that this idea of a drone-show with a system that is able to track the drones will eliminate the preparation time immediate. Drones can start where ever they are placed and the system will figure it out and 'plays'

the show and controls the drones accordingly. A path finding algorithm takes the coordinates determined by the localization system and returns the commands which are send to the drone to execute.
Automating this process by developing a tracking system will cut this time. Which makes it possible to reduce the cost of a show. As less operators have to work less time this will be a large reduction in price. The benefits of being cheaper makes the service more attractive to costumers as competitors

## Thanksgiving

We would like to thank our school for the budget to develop this project. Also for all the available equipment. We would like to thank Hay for organizing this unique experience with an extra disciple except the common electrical-mechanical combination.
A special thanks to our mentor Geert-Jan for his time sitting with us. He was very interested and enthusiastic about our project. And was also approachable for non-project related subjects.

## Literature

[1] N/A, "Connected-component labeling," Wikipedia, 11 12 2020. [Online]. Available: https://en.wikipedia.org/wiki/Connected-component_labeling. [Accessed 20 12 2020].

[2] "Right Triangle Calculator," [Online]. Available: https://www.calculator.net/right-triangle-calculator.html. [Accessed 5 12 2020].

[3] A. Rosebrock, "Detecting multiple bright spots in an image with Python and OpenCV," pyimagesearch, 31 9 2016. [Online]. Available: https://www.pyimagesearch.com/2016/10/31/detecting-multiple-bright-spots-in-an-image-with-python-and-opencv/. [Accessed 12 12 2020].

[4] api55, "How do i connect closest points toghether using opencv," stack overflow, 25 6 2018. [Online]. Available: https://stackoverflow.com/questions/51022381/how-do-i-connect-closest-points-together-using-opencv. [Accessed 13 12 2020].

[5] https://www.forbes.com/sites/quora/2013/12/23/what-makes-the-quadcopter-design-so-great-for-small-drones

# Storage of electric energy in houses

BENGUARHOU ANGUILET, MOUAD
Mechanical engineering department, team 2
Fontys university of applied sciences
E-mail: *m.benguarhouanguilet@student.fontys.nl*

BOOM, STEF
Mechanical engineering department, team 2
Fontys university of applied sciences
*E-mail: stef.boom@student.fontys.nl*

VAN DUIJNHOVEN, SHERYL
Mechanical engineering department, team 2
Fontys university of applied sciences
*E-mail: sheryl.vanduijnhoven@student.fontys.nl*

DE BRUYN, ROB
Electrical engineering department, team 2
Fontys university of applied sciences
*E-mail: rob.debruijn@student.fontys.nl*

SHOPOV, VIKTOR
Electrical engineering department, team 2
Fontys university of applied sciences
*E-mail: v.shopov@student.fontys.nl*

**Abstract:** This paper describes an innovative concept for storage of excess electrical energy generated by solar panels. It consists of a combination of mechanical storage in the form of a flywheel, paired with a lithium-ion battery pack. The proof of concept is based on research, calculations, and simulations, which determine the optimal capacity, longevity, and safety of the system for home use. It includes models of the physical design, internal architecture, and control system.

**Keywords:** energy storage, flywheel, lithium battery, solar power

## 1. Introduction

It is important that the world switches energy resources from fossil to renewable energy. Renewable energy can be directly caught from the sun or through wind. In the past, electrical energy was produced in bigger powerplants and distributed through the electrical grid. When houses produce their own electrical energy and upload it into the grid, problems can occur. The grid is not developed to allow electricity going in the opposite direction. This is a dilemma. How can houses produce their own electricity and not upload the excess via the grid? One of the solutions is to store the electricity at the houses to keep it till it is needed for use. But how should electricity be stored? For the households it should not be too expensive, and it should also have enough capacity to cover electricity use during times when electricity could not be generated. The device should have a payback time of no more than six years.

# 2. Concept Description

## 2.1 System Requirements and Constraints

The market we are aiming for is home/personal energy storage. An average household's energy consumption, energy generation (from mainstream solar panel solutions), home space, user needs have been taken into account and compiled into a comprehensive list, which aims to satisfy users' basic needs.

The size and weight will largely depend on the battery technology used – it has to be energy dense enough to allow for the requirement to be fulfilled. The type of flywheel used will also have influence. Casing materials can be plastic – for its lightness and affordability, and aluminum – for its toughness, premium finish, and lightness (compared to other metals like steel). Both are recyclable, and we can use recycled versions of these materials in order to minimize the environmental impact of the system. Longevity will depend on battery health, as flywheels do not wear out nearly as quickly. Ensuring the safest working conditions for the battery – charge/discharge rate, depth of discharge (DoD), temperature control, and battery technology are the most important factors for this.

Efficiency is another important factor for the system. It must be ensured that not too much energy will get lost in the conversion processes. We are aiming for 80%+ for the total system. This depends on flywheel design (which has physical limitations), and on battery technology. An advanced battery technology such as Li-ion will be able to achieve this goal.

The budget and pricing are essential aspects of the system. They must be appropriate for the market segment we choose and should also be competitive with other energy storage systems that are already on the market.

## 2.2 Concept Decision

After evaluating many concepts for energy storage, we needed to focus on finding the ones most appropriate for home use. The system needs to be reliable, safe, and compact. We were inspired by mechanical energy storage, which is used in the International Space Station (ISS), and decided to combine it with the well-known lithium battery, in order to achieve the appropriate capacity.

The flywheel and lithium battery are the most compatible energy concept storages for households, based on the specific requirements mentioned earlier. But due to the shorter lifespan of normal lithium batteries compared to the long lasting one of the flywheels, the final concept decision is to combine the flywheel technology with the lithium battery technology, which makes for a balanced and much longer-lasting storage system. By combining these two forms of electrical energy storages, the increased longevity allows for the system to be more affordable on the long run.

The flywheel is here designed to satisfy the short-term electrical demand in most households, for example: it is often noticeable that in most house the electrical energy demand decreases in the evening and early morning depends on occupants, but in this case the Flywheel could supply the house with the energy needed without discharging the battery. We would also want to increase our batteries' longevity by reducing the number of discharge and charge cycles. This makes our final concept, more reliable, efficient, and sustainable.

## 2.3 Calculations

### 2.3.1. Power Generation and Storage Requirements

Our research will be focused on an average household in the Netherlands. In 2018 the Dutch public health researched that the average household size is 2,1 persons. So, for our research we are going to work with a household size of 2. The average electricity usage of 2-person household is about 7,5 kWh

a day. The goal of the project is to store a maximal amount of 10 kWh so if you have a few days with less or no energy generation you still can get electricity from your storage until it is empty.
For this research, the heating of the house is excluded because the most houses in the Netherlands are connected to the natural gas network. Also, if we include the heating of the house the project goal will not be comparable. The average heating for a terraced house is 1350 m3 of natural gas a year, which equals to 13 188 kWh a year. That is 36 kWh a day, so it is not suitable for our system's intended usage.
For the estimation of the optimal solar panel installation, we make use of normal solar panels that have a size of 1.65 m x 1 m. What is resulting in a surface of 1,65 m2 per solar panel. The solar panels of this size have a usual power of 270 W.
To compensate for non-ideal conditions, we use a conversion factor of 0.85. This includes shadows, the slope of the roof, and the loss of efficiency. The graph shows how many solar panels are needed for a particular amount of power generated. To satisfy the required 7.6 kWh/day or 2.8 MWh/year, 13 panels will be needed, according to the graph. The method for calculation is the following:

$$Correction * Peak\ Power * Numer\ of\ panels = Total\ Energy$$

$$0.85 * 270W * 13 = 2.9\ kW$$

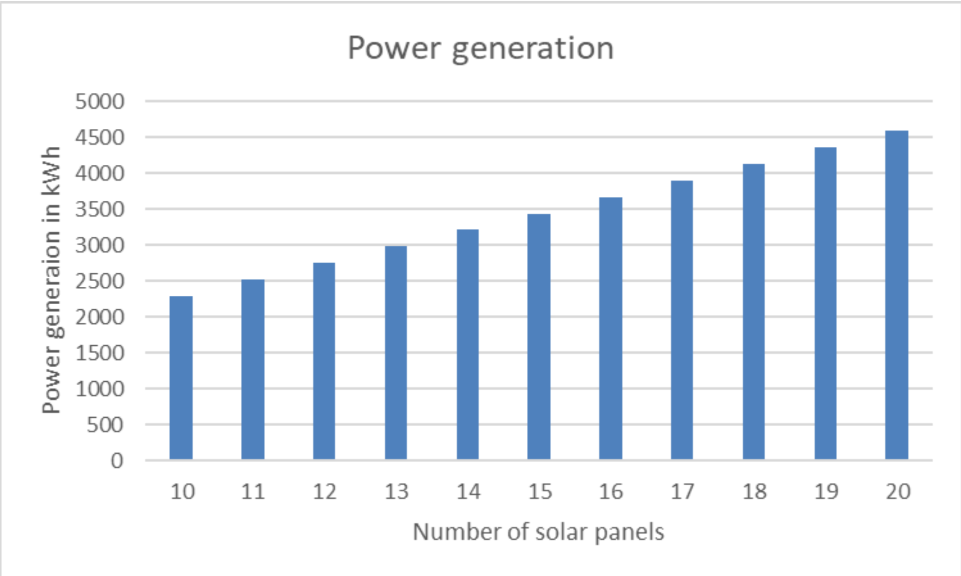



*Table 1, Power Generation Table*

### 2.3.2. Flywheel Storage Subsystem

For our project, we are designing an axial flywheel with a maximum energy storage of 5 kWh, but due to the time frame and to make our deliverable we decided to try to store at least 2.5 kWh of electrical energy that could cover the night electrical use in households. The Flywheel's size should fit within the following specifications: The diameter should not exceed 75 cm; the weight of the flywheel should be lower than 50 Kg. This Primary specification were set up by our team, to make the flywheel energy system concept lighter in weight and smaller in size compare to the conventional flywheels in the market. The main reason is due to the application of our system in households it might be necessary to move the system to different location in the same house or to a totally different household.
To determine the overall specification of our flywheel, the most important aspect is that it needs to fit the primary specifications and store around 2.5 kWh, which is approximatively 9 MJ. Trough knowing the total amount of energy to be stored, we can approximate the diameter and the weight of the flywheel compared to the rotational rate.

Flywheels store energy in kinetic form. The amount of energy stored is a function of the moment of inertia and the angular velocity, as shown in the following equation:

$$E_{rotational} = \frac{1}{2} I\omega^2 \text{ [J] (1)}$$

The moment of inertia of the flywheel is calculated based on the design of the flywheel for a solid cylinder, where m represents the mass and r is the radius of the flywheel:

$$I = \frac{1}{2} mr^2 \; [Kg.m^2] \; (2)$$

The summarized calculation of the energy to be stored in the flywheel, as well as the overall efficiency of the FESS system is represented in the following table:

| | **Weight:** | **RPM:** | **Capacity:** | **Discharge time:** | **Response time:** | **Efficiency:** | **Lifespan:** |
|---|---|---|---|---|---|---|---|
| **Flywheel** | 30 kg | 35000 | ≈ 3 kWh | 1-1800s | 5-10 ms | 75-80% | ≤20 years |

*Table 2, Flywheel Specification Table*

### 2.3.3. Lithium Battery Storage Subsystem

Different batetry technologies were evaluated for their advantages and disadvatages, and it was decided that the properties of lithium-ion (Li-ion) batteries were the most suitable for our system. The qualities, which influenced this decision was the high nominal cell voltage, high energy density, high efficiency, and long cycle lifespan, compared to other technologies like Nickel Metal Hydride (NiMH) and Lead Acid.

The minimal required  lifespan of the system is defined as 6 years. With the system recharging and discharging everyday this requires a minimum of 365 * 6 = 2190 cycles. The optimal Depth of Discharge (DoD) in order to achieve this longevity was evaluated as 60%, which will allow for up to 2400-4000 charge cycles before capacity degradation occurs [1]. When this happens after years of use, the remaining 40% will come into use as well, which will compensate for the lost capacity, increasing longevity even further.

The battery pack specifications are the following:

| | **Capacity:** | **Voltage:** | **Weight:** | **Max Power:** | **Lifespan:** | **Price:** |
|---|---|---|---|---|---|---|
| **Battery** | 8.3 kWh / 25.5 Ah at 100% DoD (5 kWh effective) | 325V | 40.5 kg | 3.7 kW | >6 years | ≈1500€ (variable) |

*Table 3, Li-ion Battery Specifications*

# 3. Simulation

## 3.1. Physical Model

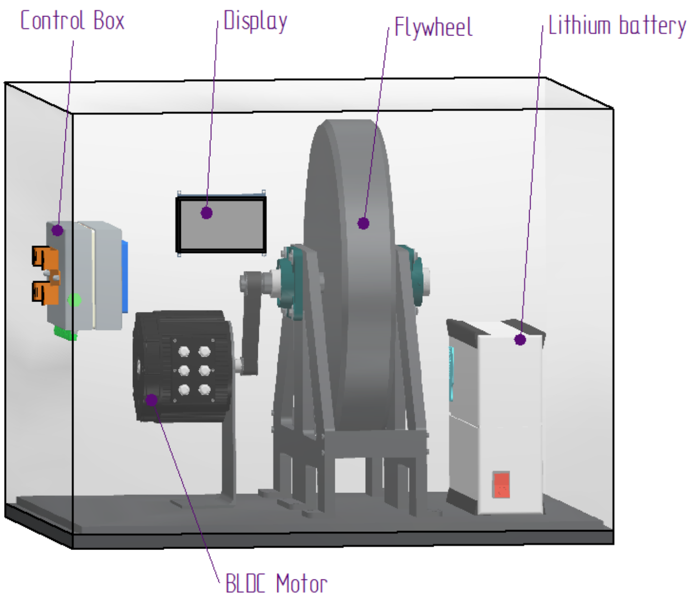



Figure 1, System Model 3D Render

To make the graphic more graphic and work towards a proof of concept a model is made to graphitize the concept. Shown in Figure 1 is the assembled model with its subcomponents. All of them are marked individually.

The entire system will take up a 1m x 1m space. Which will make the system suitable for every average basement or living room space. The wiring is left out of the model with awareness. The display has the function that for the user or the mechanic the system can be easily adjusted. Also shown in the figure is the control box which includes the control system defining a big inventive part in this energy solution. The control system brings the opportunity to store the energy more efficient by minimizing and maximizing the system output and decreasing losses.

## 3.2 Control system

The control system therefore is divided in subsystems. The structure is shown in Figure 2.

The Battery Management System consists of two subsystems – Battery Power Management and Battery Safety. The Battery Power Management subsystem monitors the charge level and sets a minimum and maximum level of charge and controls the charge and discharge rate. These functions can be influenced by the Battery Safety subsystem.

The Flywheel Management System is fundamentally similar to the Battery Management System, and it has Power Management and Safety subsystems as well. The Power Supply system consists of 3 modules: The Power Source Controller, the Mains Power Transformer, and the Solar Panel Power Converter.

The Battery Safety subsystem ensures the safe operation of the battery. It monitors the temperature of the cells and ensures that it is within safe levels, and it can also communicate to the Power Management subsystem if the temperature becomes too high. It also protects the battery from high currents and voltage spikes by sensing the input and output current and voltage. In case of an emergency, it will communicate to Power Management and initiate an emergency shutdown.

The system was simulated using Simulink. The inputs of the system are the sensors for charge and discharge current, the voltage of the lithium cells, and temperature.

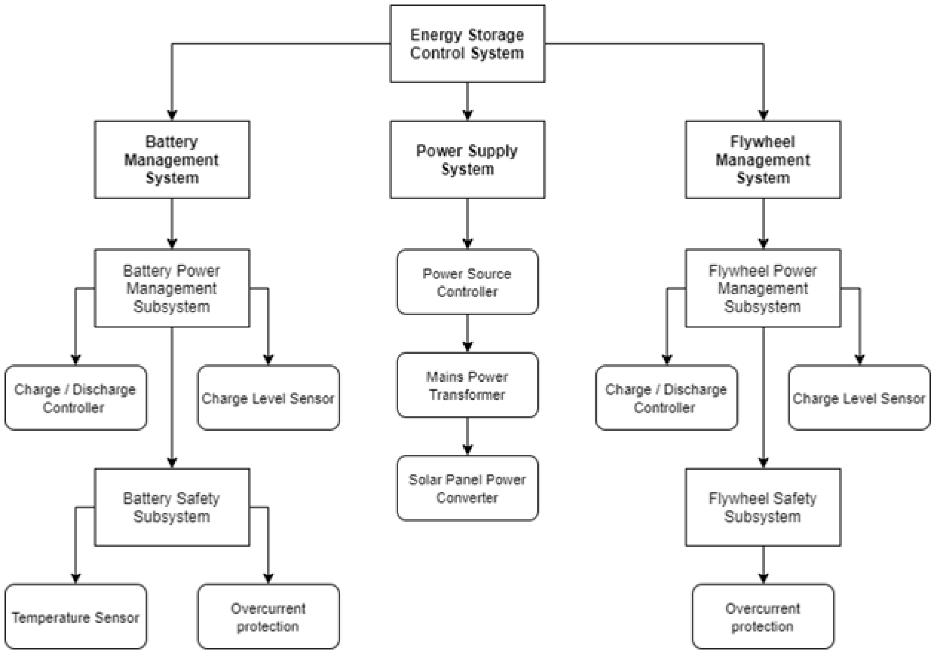



*Figure 2, Control System Flowchart*

## 3. Conclusion

We were able to create an innovative and affordable concept for home energy storage of solar power, which has the potential to popularize storing excess solar energy locally, hence lowering the load on the grid, and offering better longevity than the competition currently on the market. We achieved this by evaluating the needs of our potential users, and catering to them by selecting the appropriate technologies for our system.
The concept combines mechanical energy storage in the form of a flywheel, which is used in the ISS, with a conventional Li-ion battery pack, which are able to meet the daily energy needs of an average Dutch household. The smart energy management prioritizes the use of the flywheel, which saves battery discharge cycles, extending its lifespan tremendously. We validated our proof of concept with calculations and simulations.

## 4. Recommendations

In future iterations of this project, it would be valuable to validate the proof of concept with a physical demo. Further expansion of the control system in the form of power management circuitry will make the product complete.

## 5. References

[1] E. Winker, „Extending Battery Lifetime by Avoiding High SOC," *Appl. Sci.,* Bd. 10, Nr. 8, p. 1825, 2018.

# Different Food Packaging Concept – Innovation Engineering

Abbe Meij, Thijmen Groenveld, Martijn Kerkhof, Roko Lučin, Jos Bussel, Manon Reijbroek

Fontys University of applied Sciences, School of Engineering, Eindhoven

**Abstract:** Sustainable, durable, environmentally friendly, these are words we like to use to describe the future world we are striving for. Single-use plastics are a staggering example of the problems with a throwaway culture we created, but which has no place in our new 'environmentally friendly' world of the future. Because the amount of plastic keeps growing we need to look for ways to reduce its necessity. Food packaging is a big contributor to the plastic waste problem, because of the daily consumption everybody need. There is a lot to win with an alternative and innovative food packaging solution to reduce single-use plastics in this market. With this idea a research question was formed: ''*In which form is it feasible to find and implement an alternative innovation to reduce plastic waste in the food packaging?*'' . After investigating several concepts and ideas the best solution to reduce single use-plastic packaging is a reusable stackable box. In this box a clicking system is integrated which helps to combine several boxes for easy transportation and organizing your fridge. The boxes are useable for a variety of products and are easy to use.

**Keywords:** Food Packaging, Plastics, Environment, Innovation

## 1. Problem of Food Packaging

In supermarkets almost all the products are contained in single use plastic packaging. Some of the products even have multiple layers of plastic around it. The reason plastic is mainly used to package food items is that the plastics and the production of the packaging are cheap. the plastic packaging is hygienic and protects the products from harm from external factors.

The project a different food packaging originates from the growing awareness of the problem that the environment is being harmed and fossil fuels can run down. This project can contribute to a substantial reduction in everyday use of single use plastics, thus protecting the environment. The aim of this project is to lower the use of single use plastics in the food shopping centres. The use of single use plastics can be reduced by trying to change the shopping habits of customers or by coming up with a new concept of a food packaging.

The underlying idea of this project is to achieve a sustainable world. However, a total reversal of today's society and its customs cannot be altered in just one project or innovative idea. That's why only one of the impact factors has been chosen for this research. By finding a solution for the nowadays plastic waste issues, the plastic can be reduced.

The plastic waste caused by the food packaging is the main problem for this research. Because of that, the main research question is: *''In which form is it feasible to find and implement an alternative innovation to reduce plastic waste in the food packaging?''*

## 2. Concept Phase

To create a different way of packaging food, several concepts can be made using a morphological chart. To design a new way of packaging there are multiple options to take into account. The morphological chart helps to go through different design. To choose the best concept, the Kroonenberg method and Design of eXcellence method have been used. Within these methods the designs are grades while going through a list of requirements and categories, (Bussel van et al. 2021).
By walking through the design process by using the Kroonenburg method and the Design For eXcellence method a final concept has been chosen. The concept will be a rectangular box with a drawer. The boxes can be stacked using a form closed shape clicking system. After the boxes have been used, they are returned and cleaned to use them again.

## 3. Design Phase

### 3.1. Design choices

*Figure 3: Final concept with case and drawer*

*Figure 4: Final concept drawer*

*Drawer*
The box exists out of two parts, the case with a clicking system and the drawer that fits inside this case. The drawer can be completely taken out of the case. When the boxes are stacked in for example the fridge, the drawer can be taken out to use it where it is needed. When finished the drawer can be easily put back in the case by pushing it back in.

*Keeping the drawer closed*
The drawer has a knob on both sides. The case has similar but inverted shapes cut out on the inside. When the drawer is completely inside the box this extension of material will lock in the hole where the material is left out. Because of this locking the drawer is retained of unwanted opening.

*Taking out the drawer*
At the ends in the front of the drawer there is a hole cut out to put the fingers in for extra grip. When applying a little bit of force on these sides the knobs lose their grip on the box to ease the removing of the drawer.

Figure 5: Final concept section view of case

*Stacking boxes*
The boxes are made in such a way that they can be stacked very quickly. This helps with the transportation of the boxes and proves to be use full in neatly organizing a fridge or kitchen cabinet.

*Joining boxes*
The boxes are stacked and locked on top of each other using a shape locked locking mechanism. The mechanism is similar to systems being used in battery covers in everyday electric applications, so it should be very intuitive for users. The locking works in two parts. On one side the box has fins which fit in to a ridge of the previous box. On the other side is a leaf spring. The leaf spring is at the very top shaped in such a way that while pushing the one box on the other it will bend, but when it is finished putting on it will lock in a similar shaped hole in the other box. Now the boxes cannot be removed in the same direction as it was put on.

*Separating boxes*
To separate the boxes, you need to push the lever in the front. This lever is attached to the leaf spring locking the boxes together. When the lever is pushed the leaf spring bends in a position where it does not lock the boxes together. While pushing down the lever tilt the box and take it off.

Figure 6: Final concept clickable system

*Labelling*
For labelling the products to provide information and attract attention the top of the box is kept flat. The front of the drawer has a large space for product information as well. It is possible to use a sticker horizontally overlapping the sides of the case and the front of the drawer with a tear edge on the sides of the drawer. This could be used as a seal to see if it is unopened.

*Transporting boxes*
Besides the boxes there is a handle module. This handle can be attached and detached the same way the boxes do. When you have a tower of boxes stacked on top of each other you can attach the handle. Now the boxes can be carried around, making an extra bag redundant.

### 3.2. Materials

The boxes are going to be manufactured out of the material PA6. A couple of characteristics for the materials that have been considered are: is it recyclable, biodegradable and is it applicable for use as food packaging. (CES EduPack 2019) Another reason why PA6 has been chosen for the boxes is that it forms a great barrier between de inside and the outside of the box, this means that for example CO2 is kept inside of de box and oxygen is kept outside the box. (Promolding) The material properties that are compared between materials are for example the price, density and fatigue strength. The different materials which have been looked at are named in a list below.

- PA6
- PEEK
- PLA
- PVC
- SMA
- PMMA
- ABS

PA6 is already widely used in food contact applications, because it does not alter any structure, flavour or smell of the provisions. PA6 is safe according to the EFSA, this means that the material does not migrate into the provisions outside of the limits that are healthy. (Efsa) When used within its service temperature range the material properties do not change.
Two things have to be considered when using PA6.

- The boxes are going to be cleaned using steam. Steam can be used in a temperature range of 100-150 degrees Celsius. (Nilfisk) the maximum service temperature is 130 degrees Celsius, because of this the temperatures cannot exceed 130 degrees Celsius. This temperature should not be exceeded, because above 130 degrees Celsius the properties of the material will change and this can cause problems, such as loss of strength and chemical changes. (CES EduPack 2019)
- Studies of the Bfr (Bundesinstitut für Risikobewertung) show that PA6 used in FCM does migrate some PA6 oligomers in the provisions, but within the maximum that is healthy for the human body. Although they advise to optimise the production process to minimalize the migration of the oligomers. (BfR opinion No. 036/2019 of 17 September 2019)

### 3.3. Optimal clicking system

The most critical parts of the design are the clicking tabs. Those tabs need to be flexible enough to attach and detach boxes but also stiff/strong enough to carry the weight of the shopping products. For functionality, the chosen product must meet a minimal load capacity (10 [Kg]). This represents the extreme situation of carrying a full shopping basket.
The requirements are performed by the clicking system. To be more specific, the flexure of the tab. This flexure can be described as a cantilever with the Length (L) width (B) and height (t). This last parameter (t) can be called the wall thickness. The thickness gives the flexibility in the construction. Next to that a relieve of 20 [degrees] and grappling angle of 10 [degrees] are included. The total height of the tab (H) must be somewhat larger than 4 times the radius, so an extra 10% clearance is added. Furthermore, the radius of the tab (R), working height (H2) unlocking lever width (t2) are also design parameters. The most of these design parameters relate to (R). This to complete a fully constrained design which increases the effectiveness in the calculations.

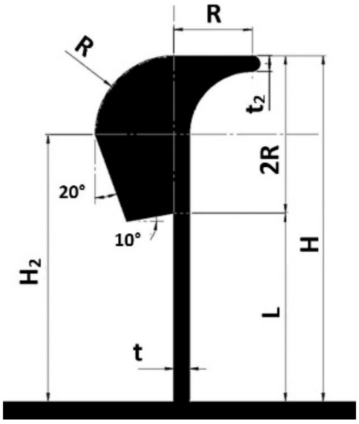



*Figure 7: Intersection of clicking tab*

The hinge has in comparison with the flexure a high stiffness and toughness. Causing by the geometrical difference. Therefor the calculations made are only for the (fragile) flexures. If the critical flexure fails, the hinge will fail as well. The stiffness of the flexure is also depending on the material specific young's modulus. Due to this difference in material properties, the wall thickness as a function of the radius will differ in each situation.
The results of the calculations are design parameters which can be used in the FEM analyses.

**Table 1:** Results of calculated critical design parameters

| Material: | $t_{min}$ [mm] | $t_{max}$[mm] | $F_{push}$ [N] | $F_{unlock}$ [N] |
|---|---|---|---|---|
| PA6 | 0.0161 | $0.273 \cdot R$ | $28.7 \cdot R$ | $15.45 \cdot R$ |
| PEEK | 0.0068 | $0.041 \cdot R$ | $7.39 \cdot R$ | $63.79 \cdot R$ |
| PLA | 0.0108 | $0.039 \cdot R$ | $4.62 \cdot R$ | $30.37 \cdot R$ |
| PVC | 0.0192 | $0.037 \cdot R$ | $0.30 \cdot R$ | $1.12 \cdot R$ |
| SMA | 0.0166 | $0.046 \cdot R$ | $16.92 \cdot R$ | $56.25 \cdot R$ |
| PMMA | 0.0111 | $0.040 \cdot R$ | $0.35 \cdot R$ | $1.04 \cdot R$ |
| ABS | 0.0142 | $0.033 \cdot R$ | $1.74 \cdot R$ | $5.13 \cdot R$ |

The values in Table 1 were verified by using Siemens NX and creating a Multiphysics solution. For this simulation a radius of R = 5 [mm] was used. According to Table 1 the force that should be applied to the tab to open it for PA6 is 15.45 times 5 which corresponds to 77.25 [N]. In the simulation that was done the maximum Force is 77.64 [N], which validates the hand calculation. Knowing that the calculation and FEM results are the same within a range of 99.5%, both methods can be used to design the final product.

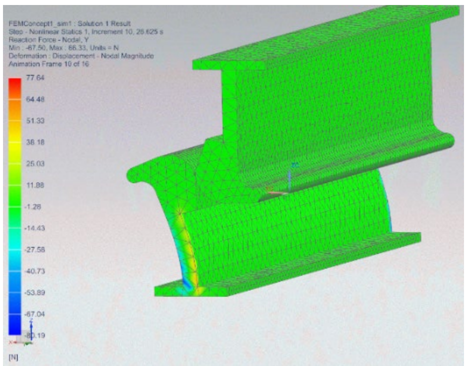


*Figure 8: FEM Analysis*

## 4. Production

Another important aspect of introducing the box in stores is the manufacturability. Since PA6 is a plastic, one of the most important ways to produce the box is by injection molding. SolidWorks offers a way of simulating molds and the way the hot plastic flows through the mold. By doing so in SolidWorks it was possible to find design flaws in the box for production. For the drawer itself the mold is quite simple, the only interesting part here were side cores. The side cores are needed because of the finger holes and the bulges to keep the drawer put in the case.

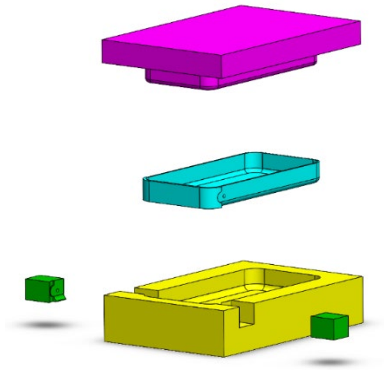


*Figure 9: SolidWorks design*

## 5. Business ability

In order to sustainable food packaging to succeed it is important to analyze the business ability. For the new concept of food packaging, it is necessary that the consumers are willing to buy a new kind of environmentally friendly packaging and are willing to pay extra. To check the consumers' willingness, several analyses can be made. This analysis is based on a survey about the "Attitudes of European citizens towards the Environment", in this survey the European citizens are distributed in several categories. Within those categories, questions about the attitudes towards the Environment are asked, (Eurobarometer, 2020).

You are worried about the environmental impact of everyday products made of plastic
One of the most important statements is about the impact of everyday products made of plastic. The question has 27498 responses, the responses are citizens of the EU. The European citizens were asked whether they are worried about the environmental impact of everyday products made of plastic. The majority of the EU respondents totally or tend to agree on this statement and are worried about the environmental impact. (Eurobarometer, 2020).

| | Number of respondents in EU per opinion | Percentage of total respondents EU per opinion |
|---|---|---|
| Totally Agree | 13253 | 48% |
| Tend to agree | 11339 | 41% |
| Tend to disagree | 2061 | 8% |
| Totally disagree | 533 | 2% |
| Don't know | 312 | 1% |

**Table 2:** Table of responses on statement: "You are worried about the environmental impact of everyday products made of plastic"

*Consumers should pay an extra charge for singe-use plastic goods (cutlery, cups, plates etc.)*

Besides the questions of the impact of plastic, 27497 EU citizens were asked whether consumers should pay extra for single-use plastic goods. The European respondents believe it is very or fairly important and agree on the statement. (Eurobarometer, 2020).

| | Number of respondents in EU per opinion | Percentage of total respondents EU per opinion |
|---|---|---|
| Very important | 9016 | 33% |
| Fairly important | 8879 | 32% |
| Not very important | 4825 | 17% |
| Not at all important | 3748 | 14% |
| Don't know | 1029 | 4% |

**Table 3:** Table of responses on statement: "Consumers should pay an extra charge for single-use plastic goods (cutlery, cups, plates etc.) "

Out of these analysis conclusions about the business ability can be made, most of the European respondents, representing the citizens, believe the single-use plastic packaging can do harm to the environment. Europeans think that the most effective ways of tackling environmental problems are to 'change the way we consume'. Therefore, environmentally friendly packaging can be interesting and help reduce the plastic waste. Most of the citizens agreed on the importance of paying an extra charge for single-use plastic goods. Because of that, they might be willing to pay extra for a sustainable good in the food packaging industry. (Bussel van et al.2021)

## 6. Conclusions

The research question was: ''In which form is it feasible to find and implement an alternative innovation to reduce plastic waste in the food packaging?''
After researching multiple designs, the best concept is a rectangular box with a drawer made of PA6. This design came out best out the Kroonenberg method and Design For eXcellence. In Siemens NX12 a simulation of the final design of the box and the clicking system has been made. The simulation has been validated by hand calculations. The values determined in the hand calculations are similar with the values of the simulations.
After doing market research it can be concluded that European and Dutch citizens are ready for changing their way of consuming products and are open to try other solutions.

## 7. Acknowledgement

We would like to thank H. Geraedts and P. van Alem for their guidance throughout the project. Their feedback and participation in discussions had a significant impact in the process.

## 8. Literature

Bussel 2021 — Bussel van, Jos; Groenveld, Thijmen; Kerkhof van de, Martijn; Lučin, Roko; Meij, Abbe; Reijbroek, Manon: "Different food packaging". Fontys University of Applied Sciences, School of Engineering, 2021.

Eurobarometer 2020 — Special Eurobarometer 501: Attitudes of European citizens towards the Environment. Eurobarometer. https://data.europa.eu/euodp/en/data/dataset/S2257_92_4_501_ENG/resource/02595d4d-dd09-413f-81c7-87f636b903ea, (2020-03-03).

Bund 2019 — Polyamide kitchen utensils: keep contact with hot food as brief as possible. BfR opinion No. 036/2019 (17 September 2019). https://www.bfr.bund.de/cm/349/polyamide-kitchen-utensils-keep-contact-with-hot-food-as-brief-as-possible.pdf

CES EduPack (2019). — [Material:\Polymers: plastics, elastomers\Plastics\Thermoplastics\PA (Polyamide/Nylon)

Promolding — Promolding: Polyamide 6 Nanocomposiet. https://www.promolding.nl/pa6/

Nilfisk — Nilfisk: Waarom reinigen met stoom de beste oplossing is wanneer hygiëne essentieel is. https://new.nilfisk.com/nl-nl/article/steam-solution-when-hygiene-is-critical/

Efsa — Efsa: Panel on Food Contact Materials, Enzymes and Processing Aids. https://www.efsa.europa.eu/en/panels/cep#:~:text=The%20Panel%20on%20Food%20Contact,food%20packaging%2C%20and%20related%20processes.&text=Chemical%20risk%20assessment%20focusing%20on,materials%20or%20other%20food%20packaging

# Reinforcing a FDM 3D print in the Z-direction

Anton Tšerepanov[1],Evyen Schouten[1],Liesje Knelissen[1],Marlies Geveling[1],Riegart Vossen[1],Antoni Vives Cabaleiro[2],Gerard Baños Esparza[2],Inés María Sánchez Jurado[2],Miquel Martos Fernández[2]

1Fontys, University of Applied Science, Eindhoven
info@fontys.nl
[2]Escola, Universitària Salesiana de Sarrià, Barcelona
eeus@eeus.cat

**Abstract:** In 3D printing the overall strength of the printed product is not similar in all axes. Due to the horizontal printing path of the printer the strength in the Z-direction is significantly lower. In some cases, this gives problems with the needed strength of products. Therefore research has been done to design a method to strengthen the printed part in the Z-direction by using reinforcing needles. The project is approached by firstly select materials for printing the base product and for the strengthening part. This resulted in a selection where PETG and Bamboo came out on top. In addition to this material selection, several injecting methods for the strengthening part are analysed. What turned out is that a strengthening method where the same material is used for the base printing part as well as for the strengthening part is the best option. Due to simplicity of the method and recyclability. This reinforcing method was further developed in order to realize an automatic reinforced printing process. The findings of this new promising technology resulted in a research to possibly start up a new company, which will be called 3D-ProldZ.

**Keywords:** FDM 3D-printing, reinforcing, injection printing, PETg, 3D-ProldZ

## 1. Introduction

Companies all want the best ideas. To create those ideas, prototyping is needed. Prototyping can be expensive when molds are needed. But a cheaper and mostly faster method to prototype concepts is to use 3D printing. Companies can easily buy a 3D printer and try to create the prototype. The easiest "at home/office" 3D printing technique is FFF printing, Fused Filament Fabrication printing. FFF printing is also called FDM printing, Fused Deposition Modelling. This printing technique will be used in this project.

FDM printing is a commonly used technique for printing concepts and repairing products. In those applications the prints are mostly custom designed for the product. It is often difficult to reuse the print after the product is disposed. Prints can be made from PLA, which is a biodegradable product, to shrink the greenhouse gas emission associated to the disposed product. The problem is that prints that are made from PLA often do not meet the required strength. Beside, this problem does not only exist for PLA, all printed materials have a weakness between the printed layers in the Z-direction.

This paper will show and select a way to improve the strength of 3D prints by inserting another eco-friendly material into the print. The main question that this report will answer is: How can the mechanical properties in the Z direction of a FDM printed product be improved while using eco-friendly materials?

Why are eco-friendly materials specified in the project? Running the project as eco-friendly as possible is important for the future. Nowadays, everything has to become sustainable and recyclable. Therefore, it is important to think of the environment when new innovative products are created. The planet continues living when this generation dies. Therefore it is important to invent products that take the health of future generations into account and thus make this 3D printing invention as eco-friendly and innovative as possible.

The main goal of the project is to run tests and find the best possible solution to strengthen the Z direction of a FDM printed product in an eco-friendly way. In order to accomplish that, first of all, additional research to the results of a previous Fontys team, which used metal as a reinforcing material, was executed (see chapter 2). Thereafter, new concepts were elaborated and tested in chapter 3 and 4. A patent research was carried out for the final concept in chapter 5. Which was followed by the description and results of the final concept in chapter 6. The business that can be build around this innovation is elaborated in chapter 7. Where finally, a conclusion is formed in chapter 8.

## 6. Injection of metal needles

In addition to work from a previous Fontys project team, first of all, their theory of injecting metal needles into a 3D printed part was investigated for its tensile strength increase.
Because of limited information of this previous work, own test samples were produced with the measurements 100x20x8mm (height, width, depth). A narrowing in the middle of the part was introduced to have a higher chance of breaking at that point(see figure 1).
For the insertion of the metal needles two holes in the centre of the sample were introduced, with a diameter of 2mm.

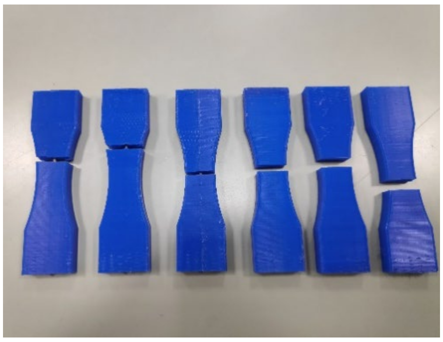


***Figure 1**: Test samples with reinforcing metal needles injected into the vertical centre axle.*

The method that was used for inserting the metal needles was taking a blowtorch and heating the needle for a few seconds. Then it was pushed manually through the hole and thanks to its temperature it melted the surrounding plastic. Table 1 shows the average results of the tensile strength tested samples.

**Table 1:** Average tensile strength of metal reinforced samples

| | |
|---|---|
| Standard solid sample | 2884 N |
| Metal reinforced sample with 2 mm hole | 3041 N |

When comparing the results it can be seen that there is an average improvement of 5.5% in strength due to metal needle reinforcement. Which is a slightly disappointing result, with even samples with less tensile strength improvement, as the above results show an average indication.

After finishing this tests there was thought about changing the insertion method, looking for a more automatic process. Therefore, a small induction machine was arranged with a copper coil to heat the samples without contact and improve the melting of the plastic around the needle(see figure 2). Also an angle was introduced to the hole in the printed samples so some tension could be distributed along the printed layers. The testing of these new samples showed an average 8% less tension than the solid ones, which means that the induction method didn't work as was expected. In order to achieve a tensile strength increase and innovational solution, new concepts were examined and introduced into the project.

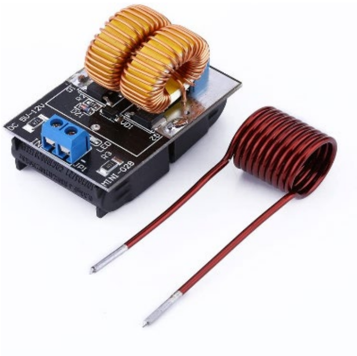


***Figure 2**: Induction machine with copper coil to heat the metal inserted needle and the sample.*

## 7. Elaboration of concept choice

The project continued after testing the metal needle injection theory of the previous research group was examined and concluded. In addition to the theory of strengthening a 3D print, sustainability and eco-friendliness were taken into account to make an innovative step. In this way the metal injection was rejected and other more eco-friendly ways of reinforcing where investigated. This chapter will describe the steps that were taken during this concept generating process.

First of all, the most eco-friendly base printing material was examined. PETG is chosen as the most fitting material to use for this project. The material is easy to manufacture, safe to use, sustainable and recyclable. The first idea was to use a PLA material as it is biodegradable. However, this idea had to be reconsidered as biodegradable is not as eco-friendly as recycling PETg(Fontys IE4, 2020).
In contrast to PLA, PETg can be recycled multiple times without losing properties. This is a good step into the direction of a circular economy.

Secondly, the reinforcing material was investigated. Sustainability was a key term to select materials. In this way bamboo needles were suggested, as bamboo has a high tensile strength, has a low ecological footprint and is biodegradable. A negative part of using bamboo into a polymer printed base is that the combination of these materials produces a composite. Which is relatively hard to recycle.
The only way to prevent creating a composite is by using the same material for the reinforcement as for the base. In this way it became attractive to look also for options to create a reinforcement out of PETg. Both selecting processes are visible in Appendix A. Bamboo and PETg where both further implemented into the next step, which was creating and testing samples.

## 8. Testing concept choices

The goal of this chapter is to describe the testing process and its results. The testing method will be described in §4.1. In addition to this testing process, the results are presented in §4.2.

### 4.1. Testing method

First of all, about 30 samples were printed out of PETg. Holes were already created in some samples during the printing process. The measurements of these samples are visible in table 2.

**Table 2:** Measurements of printed test samples

| | |
|---|---|
| **Length** | 100 mm |
| **Width** | 20 mm |
| **Thickness** | 8 mm |
| **Layer thickness** | 0.2 mm |
| **Hole diameter (optional)** | 2 to 5 mm |
| **Bamboo and PETg filament diameter** | 3 mm |

Reinforced samples have a hole in the middle along the length (normal to the layers) that is filled with Loctite epoxy 3090 to glue bamboo skewers and PETg filament into the hole. There was no other option for introducing the reinforced material yet, because the bonding was simply not strong enough. The samples are shaped in a way that the clamping parts of the samples are wider to induce braking in the middle of the sample (see figure 3). Fully prepared test samples are visible in Appendix B.

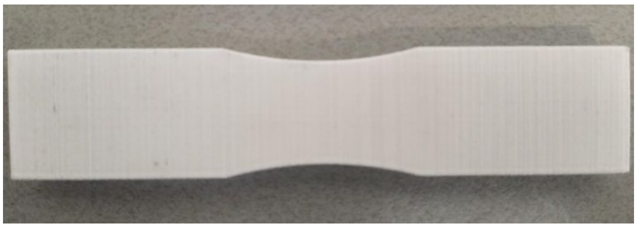


***Figure 3**: Printed PETg test sample*

The tests of these samples show promising results (see figure 4). Samples with an insert of a filament or bamboo show improving properties towards the ultimate laying reference sample, both in strength and strain.

Figure 4 summarizes the results where improvements are indicated. One can see that laying orientation provides a strength of 141% higher than standing prints.

Reinforced samples show increase in strength of 69% and 96.3% for polymer and bamboo inserts, respectively(Fontys IE4, 2020). More detailed results are visible in Appendix B.

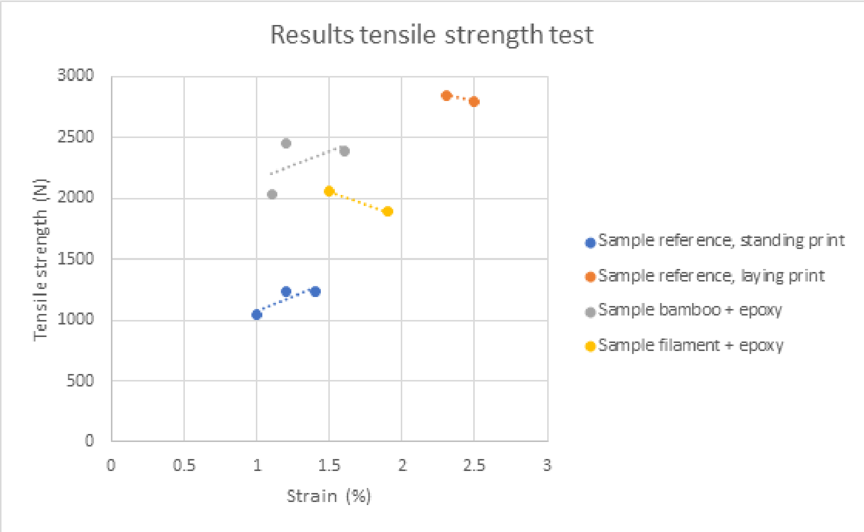



***Figure 4**: Tensile test results for reference and reinforced samples of 3D printed parts*

### 4.2. Conclusion of testing

Based on the information above, the proof of concepts show promising increase in tensile strength. It is interesting to see that the filament reinforce samples have a significant increase in tensile strength. This can provide options in working towards a mono material reinforced product, which is easier to recycle. Therefore, the bamboo reinforced theory was rejected and full focus was set on creating a PETg strengthened part. In order to create a proper innovation, the goal is to inject the same filament as used for the printed part while it is printing, and thus remove the post processing step. This creates a next problem, namely, how this process can be automated.

## 9. Patent research

In order to introduce a new technology into the market it is important to research if it does not violate patents of other researchers or companies. Therefore, a proper patent research has been executed to investigate if a similar technology, of which uses a reinforcing 3D print process is already patented. Patents were investigated before elaborating the final concept as it could prevent doing a lot of extra work. This patent research is briefly elaborated in this chapter.
The research resulted in three relevant patents that were found. These patens have a few claims that had to be considered when the final concept was elaborated, but none of the patents have so much in common with the concept that it is not patentable.
The first patent (see figure 5A)(USA Patent US2020198249A1, 2018) that was found describes a form of casting a ceramic material into a 3D printed shell. The fact that it uses a 3D printed base while casting a fluid that ultimately hardens inside is similar to the concept of the project team. However, the patent that was found fills all of the print with a second material, which makes the part a composite.
The second patent (see figure 5B)(China Patent CN107984749A, 2017) also prints a base where another material will be injected, but this patent uses a resin as the injected material. Furthermore, the concept uses multiple basins next to each other that will be filled.
The third patent found (see figure 5C)(China Patent CN108284592A, 2018) is the most similar to the concept of the project team. It injects a polymer into a hole within a 3D printed part to increase the strength of the product. The patent uses a different material to insert than the base material, which makes it possible to use the difference in glass temperature to insert the needle. It also uses a fan that moves the heated air trough the whole hole. In this way, the temperature difference between a point at the beginning of the hole and at the end of the hole is reduced. This is essential for the properties

of the material. This patent makes it impossible to use the idea of extruding polymer needles of a different material into holes.
To work around this patent the needles can be inserted by putting a solid needle into the hole and let it bond to the base material by making the outer layer more adhesive. This can be done by heating that layer or by using a chemical like ethyl acetate. In the end, this concept was not significantly elaborated because it would not bring much new innovative results into the world.
The final idea, which prints small reinforced needles during the 3D printing process does add new value to the FDM print technology field. As this technology can be used to increase the strength of 3D printed parts while ultimately using the same amount of time as needed to print parts that are not reinforced. Furthermore, the reinforcing needles are made of the same material as the printed base. Which prevents creating a composite product which is hard to recycle. This type of concept has not been patented yet, which means that it can be elaborated during the project.

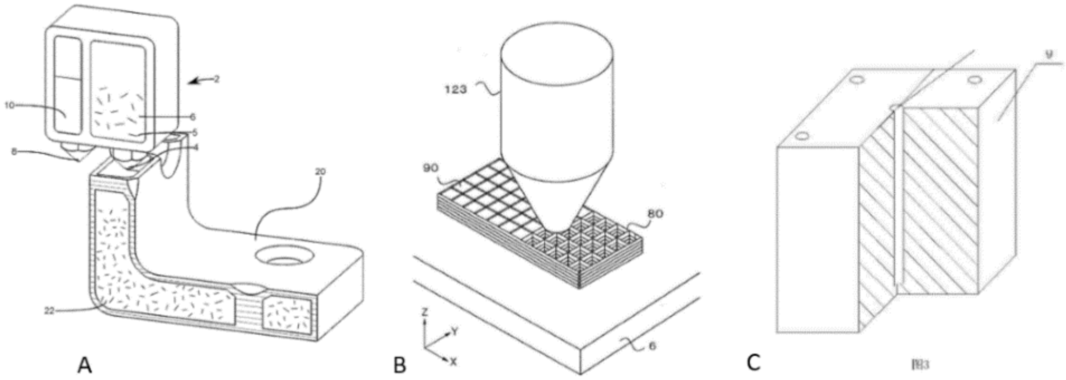



*Figure 5: Illustrations of the patents that are similar to the researched concept.*

## 10. Elaboration of final concept

The final concept is elaborated in this chapter. A brief concept description will be shown in §6.1. Furthermore, simulations of the process were executed and described in §6.2. Finally, first results and possibilities of this technology are visible in §6.3..

### 6.1. Concept description

In order to produce printed products that are recyclable, the continuous fibers that form the printed layers and the short fibers that are positioned perpendicular to form the strengthening needles need to be made out of the same material, as it will be better recyclable. The material that is used is PETg. A final inventive technological solution was invented because a good adhesion between the base material and the needles was difficult to achieve after the base was printed.
This new idea inserts shorter needles during the printing process by using a second printer head. An additional advantage of injecting the needles while printing the base is that it reduces the production time. Furthermore, it can be implemented into products with difficult geometries. Next to that, this method can be used on existing FDM printers with two printer heads.
This method uses conventional workflow as a base. The part is designed as usually, exported to a format that a slicer can read (like a .stl format or any other alternative) without changes, and imported to the slicer. In the slicer, parametric holes are created inside of the part which are at least a few printed layers tall. The holes are then going to be filled/injected with molten polymer during the printing. When printing, the printer head will stop at each layer where the holes are finishing, and a second nozzle (with modifications, or even a standard nozzle) positions itself over the middle of the hole and injects the plastic in the hole with the parameters that are also pre-set (see figure 6 and Appendix C).

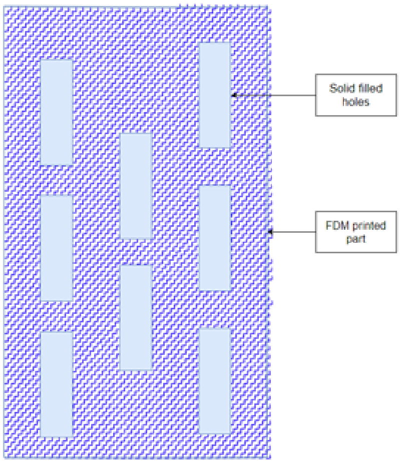



*Figure 6: Concept visualization*

### 6.2. Simulations of the concept

The challenge is to characterize the injection process from the temperature perspective as it is the most important parameter that affects the viscosity and thus the quality of the injection of the polymer. Characterization is considering both geometry of the hole and nozzle(Bandhari et al., 2019). Simulation models were built where the injection hole and surroundings are modelled as simplified blocks. More details on geometry and parameters can be found in Appendix C.
The injected polymer temperature is measured along the middle of the injected polymer.
Figure 7 shows the results of the temperature profiles for different scenarios of the parameters. The hot end temperature is set to a realistic printing temperature for FDM printers of 250°C, environment temperature is set to 60°C, and material is set to ABS, for the lack of PETG in the materials library of the NX12. Material choice does not affect the comparative study of parameters but rather the magnitude of the difference due to different thermal conductivities of the two. The most important groups of experiments to notice are Nr. 1-3, 4, and 5-7. Parameters of the experiments can be seen in Appendix C.

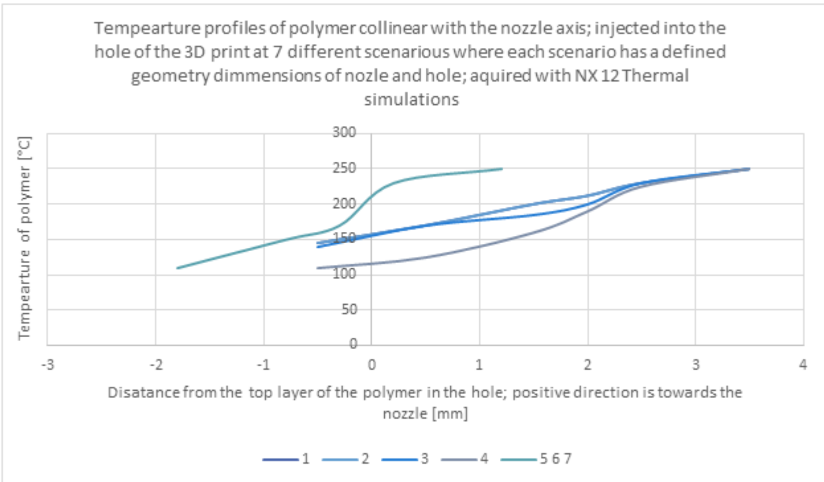



*Figure 7: Temperature profiles in the middle of the polymer stream through the nozzle and further into the printed part.*

Results suggest that the biggest effect on temperature profile has the distance of the nozzle to the top surface of the injected polymer. At a distance of 2.5 mm from the surface of the injected polymer to

the nozzle, the temperature drop was 135°C at the worst-case scenario and 100°C in the rest of the cases. At a distance of 0.2 mm the temperature drop was 30°C.
Additionally, proportions of the polymer that is injected and the air gap size between injected polymer and walls of the hole are playing an essential role resulting in the 35°C difference at the bottom of the hole.
Conclusion is that to achieve a lower temperature drop and thus higher chance of a good injection, the nozzle has to be as close to the bottom of the hole as possible in order to have the smallest temperature drop as possible.
Further investigation into injection parameters is required like injection speed, temperatures of nozzle and environment, hole and nozzle geometries, and other relevant parameters to ensure the best injected polymer quality of material and bond to the printed part. Understanding the temperature profile behaviour was the first and most important step in describing the process.

### 6.3. Results & possibilities

This technology was further tested by created test samples. These test samples had the same measurements as the previous samples with the bamboo reinforcement. Printing these samples proved that it was possible to use the concept and produce samples of a decent quality. These samples are visible in Appendix C.
It is then interesting to compare these new samples with the previous proof of concepts with the glued PETg filament in it. These samples showed an average tensile strength increase of 69%. To achieve similar results on a printed part straight off the printer, the injection of polymer with the standard/or modified printing nozzle in the middle of the printing process was proposed. In the previous paragraph characterization of the injection process from the temperature of injected polymer point of view showed that the nozzle has to be as close as possible to the bottom of the injection hole showing 70°C difference between distances of 0.2mm (30°C drop) and 2.5mm (100°C drop). This has been attempted as best as possible when adjusting the printing parameters.

Further testing was done to research if the tensile strength increased due to the reinforcing method. The testing results were inconsistent but promising. The maximum strength result of these samples is 2510 N. This means that almost an identical strength as the bamboo reinforced samples is possible. Although, the results are to inconsistent to conclude that now. Therefore, further testing is necessary, which is till an unknown date not possible due to circumstances that can not be influenced by the project team.
This invention can be further worked out and eventually sold as a software license. Therefore, a G-code of the printer has to be written that prepares the STL files of to be printed products by calculating the correct placing and temperature for the holes and second filament that will fill them. In this way all kinds of reinforced products can be printed, like the handlebar that can be seen in Appendix C.

## 11. Business plan

This chapter is all about the Business plan, the approach of the start-up and the future view of 3D-ProldZ, the name of the new company. 3D-ProldZ is a combination of the three terms. Which are, 3D-printing(3D-Pr), injection moulding(old) and Z-direction(Z), which refers too the strengthening in the Z-direction of the print. These are three key concepts that stand for this company.
In terms of tradability 3D-ProldZ can sell licenses to companies who want to make use of this technology. In this way companies can develop their own strengthened products. Furthermore 3D-ProldZ can set up an own production line where reinforced products for all kinds of applications can

be used. Think of specific prototypes, custom designed parts or mass production of enforced parts. Therefore, 3D-ProldZ can sell their goods to businesses(B2B) as well as to private consumers(B2C).

The Business Model Canvas (see figure 8) is a model for strategic management and lean start-ups to create a new business model or to edit an existing one. It also shows the added value of a company and how to create, maintain and deliver this value throughout the years. The Value Proposition canvas is being used to basically see through the eyes of the customers what makes the company distinctive from others. This is also the most important aspect of the BMC(Fontys IE4, 2020). In figure 8 is illustrated what the look on the market is, what is needed to enter the right market, and the relationship with the customer. This is an overview of the what makes 3D-ProldZ a company.


***Figure 8**: Business Model Canvas 3D-ProldZ*

From the balance sheet of the first year, an estimated profit is made for what investment is needed in order to keep 3D-ProldZ and their employees satisfied. With a bank loan of 9.700,- there will be a profit of 1864,31,-. In order to achieve this profit licenses will be sold the first year. Those licenses cost 1.920,- per year and 160,- per month. It will be expected to sell 5 licenses and 40 products in the first year. Those products will cost around 88,-, also depending on their geometry. Also there will be invested in a patent for 6.914,- in the first year(Fontys IE4, 2020). In this way 3D-ProldZ can protect their innovative technology for the competition.

## 12. Conclusion & recommendations

The original project goal was to find an eco-friendly solution that strengthens a FDM printed product in the Z- direction while using fibers or needles, e.g. bamboo needles. This goal was changed during the project. The eco-friendly materials changed to an eco-friendly solution and this influenced the end product. In the end, the project was not only about 3D printing with an eco-friendly material, it was also about thinking of an eco-friendly solution for strengthening the print. The solution that is proposed is recyclable, stronger and easy to implement.

The solution is to print the product with internal holes in the z-direction. That hole is filled in a new way, based on the injection moulding technique. The concept prints a part of the print, keeps the holes inside of the prints open and fills it at the optimal height with a 'solid' material, also printed as filament. The product that is created consists of a mono material, a strengthening method that strengthens the 3D print with the same material, by using the hole filling technique.

The printing process that creates the reinforced product is going to be sold, in the form of a license. Individual products can also be requested and printed.

Some aspects of this technology can still be improved. The recommendations for improvement will guide the future of the project in the right direction.
The first recommendation is more testing. The concept is tested with limited numbers of samples and there where some staggered results. The spread in the results makes the conclusion less reliable. Increasing the number of tested samples will most likely decrease or minimalize the staggered results.

The second recommendation is testing the concept with different materials. Does this concept also work for PLA or PET or ABS? If it also works for other materials the market grows and it can be used in multiple areas.

Another recommendation, the third is to investigate the recycling process of 3D printed products. At the moment it is known that it happens and that companies do this, but limited information is available. New information about the recycling process might contradict the negatives that the needle concept has.

The last recommendation is doing research for the G-code and the automation process. This concept is based on ideas and assumptions. The companies that were contacted that have the knowledge to help/share knowledge didn't reply properly on the question if they could help this project by designing a G-code, so this is one of the future steps to realize and finish the final concept.

## Acknowledgement

The project team would like to thank dr .ir. B. Huis in 't Veld and dr. Pablo Sevilla for guiding us through this project with their useful feedback and support. The team would also gratefully acknowledge the assistance of companies Blue Engineering and Colorfabb for sharing their knowledge and providing feedback on our decisions.

## 13. Literature

Bandhari et al., 2019 — S. Bandhari; R. Lopez-Anido; D. J. Gardner, „Enhancing the interlayer tensile strength of 3D printed short carbon fiber reinforced PETG and PLA composites via annealing," Elsevier B.V. , 2019.

Fontys IE4, 2020 — Geveling, Marlies; Knelissen, Liesje; Schouten, Evyen; Tserepanov, Anton; Vossen, Riegart; Business plan 3D-ProldZ. Fontys, University of Applies Science, 2020

| | |
|---|---|
| Fontys IE4, 2020 | Geveling, Marlies; Knelissen, Liesje; Schouten, Evyen; Tserepanov, Anton; Vossen, Riegart; Strengthening a FDM 3D-print in the Z-direction. Fontys, University of Applies Science, 2020 |
| Fontys IE4, 2020 | Geveling, Marlies; Knelissen, Liesje; Schouten, Evyen; Tserepanov, Anton; Vossen, Riegart; Testreport strengthening PETg. Fontys, University of Applies Science, 2020 |
| Vivek et al., 2018 | D. R. Vivek; B. Madigan; M. J. Cola; M. S. Piltch, „Method of manufacturing isotropic parts utilizing additive manufacturing methods". USA Patent US2020198249A1, 19 12 2018. |
| Yoshiyuki et al., 2017 | B. Yoshiyuki; M. Hitoshi; Y. Kiyoshi, „Method of producing three-dimensionally shaped object and three-dimensional shaping apparatus". China Patent CN107984749A, 25 10 2017. |
| Yumei et al., 2018 | D. Yumei; J. Zhiwei; L. Rongjun; L. Chauqun; L. Youzhi; M. Haopeng; Y. Weimin; Y. Yong, „Combined machining device and method based on 3D (Three-dimensional) printing technology". China Patent CN108284592A, 22 03 2018. |

## Appendix A: Material selection methods

In this appendix, the material selection graphs can be found that were briefly named in chapter 2. First of all, the different materials that were taken into account for creating a printed base are compared to each other (see figure 9). PETg was chosen as the most fitting material to use for this project.


***Figure 9**: Material selection for the printed polymer base*

Further material selection was carried out for the reinforcing material (see figure 10). Bamboo was the material that came out on top. Because of its low cost, safety and recyclability.

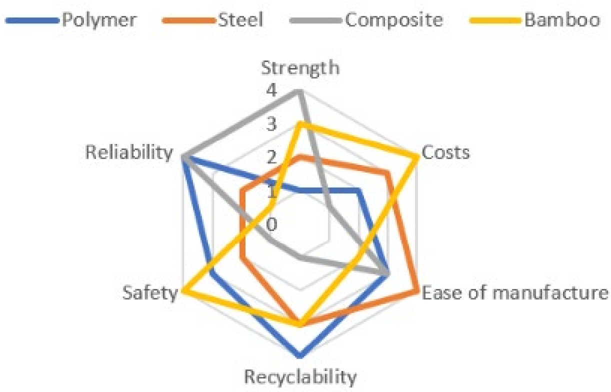



***Figure 10**: Material selection for reinforcing material*

## Appendix B: Testing samples & results

This appendix shows the test samples and materials that were use in order to prepare the testing of proof of concepts. Furthermore, additional results are shown for a more detailed overview of the strength improvement.

Printed PETg test samples were prepared were PETg filament was glued into a prefabricated hole. The glue that was used was Locktite 3090 (see figure 11). The second sample version was created by gluing a bamboo skewer into a prefabricated hole (see figure 12). This resulted in two different kind of test samples that could be tested.

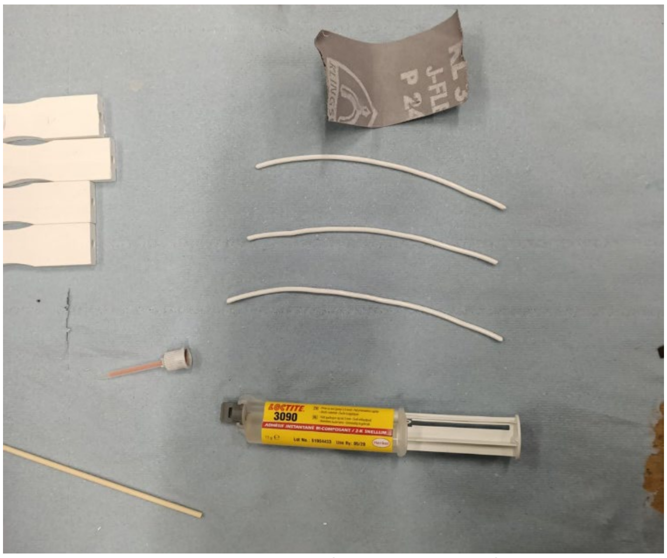



***Figure 11**: Materials to prepare test samples with PETg filament as reinforcement*

***Figure 12**: Test sample with a glued bamboo skewer in the printed base sample*

Results of testing the samples are collected and summarized (see table 3). The reinforced samples show a positive increase in tensile strength. Which confirms that this theory of reinforcing is effective.

**Table 3:** Results of tensile strength test with reinforced samples

| Sample name | Average Force [N] | Average Stress @ area of 160mm^2[MPa] | Improvement [%] |
|---|---|---|---|
| Z-Reference – tensile stress normal to the layers | 1173 | 7.3 | 0 |
| Z-Reference + Filament insert | 1975 | 12.34 | 69.0 |
| Z-Reference + Bamboo inserts | 2293 | 14.33 | 96.3 |
| XY – reference – Tensile stress parallel to the layers | 2825 | 17.65 | 141.1 |

## Appendix C: Final innovation concept

This appendix shows further simulation and test results that were addressed in chapter 6.
A schematic drawing of the automated process is visible in figure 13. This drawing identifies the extruder, nozzle, polymer base and injected polymer. It is visible that a prefabricated hole in the base part will be filled by an injected polymer. This injected polymer will have a higher tensile strength because layer adhesion will be increased in this part.

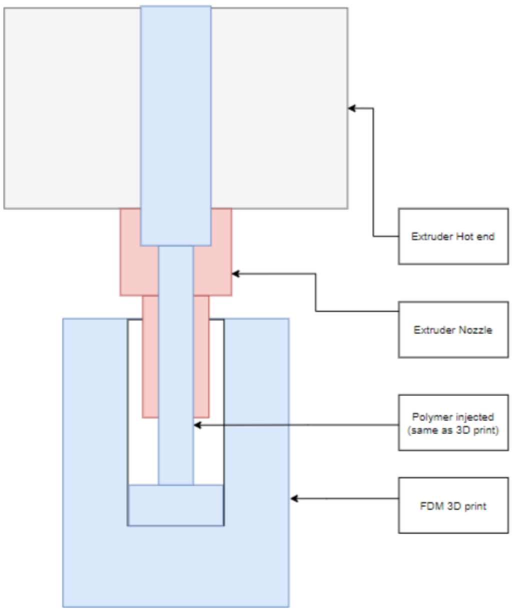



*Figure 13: Schematic drawing of automated reinforced printing process*

Further CAD and FEM drawings were produced with Siemens NX12 (see figure 14). The injected polymer temperature is measured along the middle of the injected polymer (orange circles). This simulation clearly shows a significant temperature drop within a short distance.

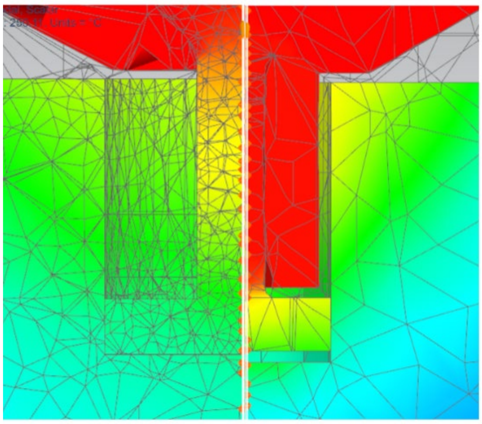


*Figure 14: Simulation screenshot (NX12) of the nozzle with filament filling 25% of the hole; Left is standard nozzle, and Right is a modified nozzle that goes in the hole.*

In addition to this thermal simulation, table 4 was created to visualize the temperature drops due to an increasing nozzle distance. The relation between those factors is visible in this table.

**Table 4:** Summary of the parameters for the groups of the experimental results

| Nr. Of Experiment | Nozzle distance from the top of filament in the hole to the nozzle [mm] | Gap size between the filament and the hole diameter [mm] | Temperature at the top of filament in the hole [°C] | Temperature drop from 250°C [°C] |
|---|---|---|---|---|
| 1-3 | 2.5 | 0.2-2 | 150 | 135 |
| 4 | 2.5 | 2 (worst case; biggest gap, the least amount of filament) | 115 | 100 |
| 5-7 | 0.2 | 0.2-2 | 220 | 30 |

Because it was important to check the feasability of the technology in real life, test samples were produced (see figure 15). It is visible that the reinforced polymer was injected nicely in the prefabricated hole, layer by layer. This gave confidence prior to the tensile strength test.

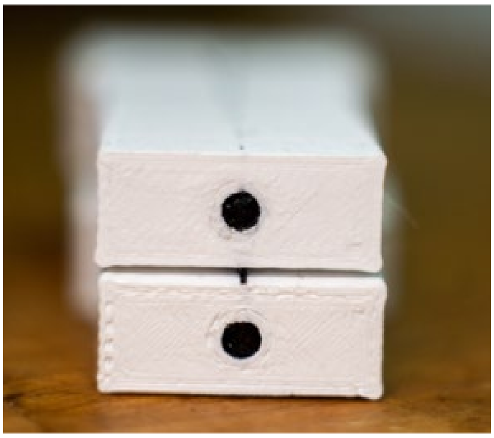


*Figure 15: Test samples that were produced with the automated printing process.*

These samples were eventually tested to gain results about their tensile strength properties(see table 5). Although inconsistent due to the limited number of test samples, it is visible that a strength improvement is possible with this technology. Further testing is needed to gain more knowledge about the best printing parameters and testing properties. This is only possible when the testing labs will open again in a short period of time.

**Table 5:** Tensile test results of automated reinforced samples

| No. | $L_{0\,Stand}$ mm | $L_{0\,CH}$ mm | $L_0$ mm | Curve | $E_t$ MPa | $\sigma_x$ MPa | $\sigma_y$ MPa | $\varepsilon_y$ % | $\sigma_m$ N | $\varepsilon_m$ % | $\sigma_b$ MPa | $\varepsilon_b$ % | $\varepsilon_{tb}$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 40,11 | 50,12 | 40,11 | Type a | 329 | - | - | - | 1790 | 0,80 | 11,2 | 0,80 | - |
| 2 | 40,09 | 50,06 | 40,09 | Type a | 44,1 | - | - | - | 1970 | 2,2 | 12,3 | 2,2 | - |
| 3 | 40,10 | 50,10 | 40,10 | Type a | 74,9 | - | - | - | 2480 | 1,7 | 15,5 | 1,7 | - |
| 4 | 40,15 | 50,09 | 40,15 | Type a | 102 | - | - | - | 1930 | 2,2 | 12,0 | 2,2 | - |
| 5 | 40,06 | 50,16 | 40,06 | Type a | 163 | - | - | - | 2510 | 2,0 | 15,7 | 2,0 | - |
| 6 | 40,14 | 50,24 | 40,14 | Type a | 62,1 | - | - | - | 1180 | 1,8 | 7,35 | 1,8 | - |
| 7 | 40,09 | 50,09 | 40,09 | Type a | 64,7 | - | - | - | 1490 | 1,7 | 9,31 | 1,7 | - |
| 8 | 40,07 | 50,00 | 40,07 | Type c | 77,9 | - | 2,02 | 6,4 | - | - | - | - | - |

A first product that has been designed with this technology is a handlebar for a suitcase(see figure 16). It is a first beginning of implementing this technology into the 3D printing industry. Ones production is started, possibilities are endless for using it in other products and industries.

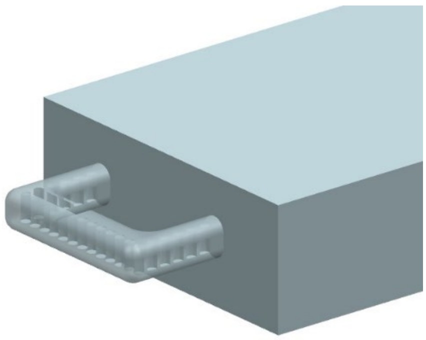


***Figure 16**: Handle bar that has been designed for implementing the new automated reinforced printing technology.*

# Smart Mobility for Cities: Autonomous E-Scooter

Aleksandar Durić[1], Daan Kruidering[1], Dania Elokda[1], Leon Visperas[1], Martijn Huijbregts[2]

1Department of Mechanical Engineering, Fontys University of Applied Sciences, The Netherlands, Eindhoven
2Department of Mechatronics Engineering, Fontys University of Applied Sciences, The Netherlands, Eindhoven

a.duric@student.fontys.nl, d.kruidering@student.fontys.nl, d.elokda@student.fontys.nl, l.visperas@student.fontys.nl, martijn.huijbregts@student.fontys.nl

**Abstract:** This paper details the design and innovation process of a smart mobility solution for future cities where the use of private vehicles will be banned. The main question of the paper is "*How can the e-scooter be designed to satisfy the conditions of being autonomously driven and controlled via an app?".* The paper details different elements of the project such as patent research, sustainability, innovation techniques, conferences, tech trends and market research. The conclusion of the project is to design a three-wheeled electric scooter based on a pre-existing design created by Fontys. This scooter would incorporate a multitude of sensors for autonomous operation and would be controlled via an app. Through this app users will be able to book and call scooters to their location so they can commute through the city to their main transport.

**Keywords:** Autonomous, e-Scooter, mobility, transportation

## 1. Introduction

As the human population continues to increase and city centres are getting more and more crowded; there is less and less space. To solve the issue of decreased available space, cities are planning to ban and/or restrict the private use of automotive vehicles within the city centres [1]. This is being done to reduce the emissions and therefore increase the air quality within cities. This will create room for more infrastructure as the conventional public roads can be transformed.
This opens new opportunities for a modernized and more effective mode of transportation within cities. Commuters will now need to travel through the city and into the city using different forms of transportation. In order to create a convenient solution for transportation, the idea of an autonomous scooter which can drive to and from the user's location was generated. This allows for a minimal number of scooters with smaller batteries that can charge themselves in dedicated stations.

## 2. Product Innovation

### 2.1 Innovation Basics - Problem Description

#### Problem Summary

Cities are getting more and more crowded and the road system as we know it today is being overloaded. To aid the reduction in traffic jams, gridlocks and air pollution caused by diesel and petrol-fuelled vehicles, cities have been limiting the allowance of car entries into their city centres. In the future, several cities also plan to eliminate all personal automotive travel within city centres to reduce the occupied space by the roads and parking areas. Therefore, a new form of transportation is needed to travel within city centres.

**Solution Summary**

Current scooter shared systems have only one type of scooter to transport people through varying distances and weather conditions. They also contribute to scooters being used at will and left around cities away from charging stations which causes a need for many scooter collections and charging actions. This is evidently inefficient because it can have detrimental polluting effects on the environment and since short-range trips still use a scooter with a large capacity battery. In order to overcome this challenge and eliminate the unnecessary greenhouse emissions produced throughout the transportation phase of an e-scooter to its charging station, the idea of designing an autonomous e-scooter that is controlled via an app was developed. The main research question that stems from the problem definition serves to tackle the overall goal of this project and is as follows:

"*How can the e-scooter be designed to satisfy the conditions of being autonomously driven and controlled via an app?"*

**Creativity Invention – TRIZ Method**

The use case of the problem can be analysed using the TRIZ Model shown in *figure 1*. Here, the past of transportation in this sector is comprised of cars, bicycles and walking. The trend of public shared transportation is emerging and the ban of gas and diesel powered vehicles in cities catalyses the need for alternative transportation options. The specific situation shows the current emergence of electric scooters; however, these are limited in possible extended/public uses. The intermediate stage will be the autonomous e-scooter which is designed for fast recharging due to the possibility of travelling to and from a user and the charge station. This allows for specific users use case without the nuisance of storage, initial cost, and ownership for the user. The final solution is derived by using the automated solution and the electric scooter solution and combining them to solve the specific problem.

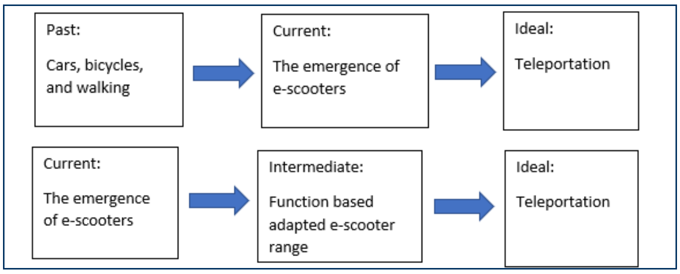



*Figure 10 Triz Methodology*

*Table 4 Contradiction Matrix*

| Worsening Feature → / Improving Feature ↓ | | 1 | 38 |
|---|---|---|---|
| | | Device complexity | Extent of Automation |
| 36 | Device complexity | | 23, 28 |
| 38 | Extent of Automation | 28 | |

The contradiction matrix in Table 1 takes parameters 36 and 38 into account. The weather protection system and autonomy required for the new e-scoter requires increase of device complexity and these aspects create a contradiction. For an improving complexity and worsening of automation extent, inventive principles Feedback(23) and Replace mechanical systems(28) provide the most feasibly solutions. For an imporving extent of automation and worsening device complexity, invetive principle Replace mechanical systems(28) prove to be optimal. The usage of the ideality equation (1) allows implementation of the proposed solutions.

$$Ideality = \frac{\sum Benefits}{\sum Costs + \sum Harm} \qquad (1)$$

**Sustainable Development**

The main goal of this project is to create a product that is sustainable whilst still ensuring that it performs the desired tasks. In order to design a product in this way, several sustainability design techniques where considered. Firstly, the scooters are designed for repair and improvement meaning they are designed to remain on the streets without being needing to be replaced. Instead, the service would be improved or modified to meet new market demands or challenges. By doing this, the product would be built under the concept of circular economy where waste is minimized through continually using available resources. The second design consideration towards sustainability is the use of smaller batteries. Unlike most scooters available in the market today, this design will incorporate a battery pack providing a range of up to 10km only. This means smaller batteries are needed and hence less pollution is created in the battery production phase of the lifecycle. Because the scooter is autonomous, it will constantly keep returning to a battery charging station when not in use and hence would have an effective range necessary for keeping up with demands whilst having a smaller battery than conventional scooters.

**Patent Research**

To receive a patent, a design or process must be unique in its operation and/or design. The autonomous e-scooter uses two existing designs namely that of the scooter and the principle of automation. In addition to that, there are specific design elements to be considered such as the balance control system, a user-friendly app, a weather protection system, and the software running it. The system as a whole is not patentable since it is a system derived off other pre-existing systems; however, individual parts can be patented.

ESPACENET is a patent database where most of the worlds' patents can be found. To determine the patentability of the design, ESPACENET was used through several steps. Keywords related to the project were used in the query search. These words were 3-wheeled, self-driving, gyroscope, scooter, autonomous, self-balancing, four-bar system, camera array, GPS, navigation, and accelerometer. All the patents related to these keywords were then noted. Next, the keywords were refined to remove duplicates and to remove any words which resulted in irrelevant query answers. The search was refined further and the final patents which may relate to our design were also noted. A patent expert was then contacted and shown the design as well as the patents we believed to be relevant. This discussion lead us to the conclusion that the whole design cannot be patented. However, after developing a prototype, certain aspects of the design can be patented.

If the system includes aspects such as an innovative software, app design or balancing system, this can be patented after its design. A patent requires a design and explanation; however, as this project is working only with a proof of concept, the only patentable part would be a unique linkage system. Due to time and financial constraints, the linkage system uses a four-bar coupling system and is therefore not patentable. If further development are to be made on the project, it would be advisable to acquire patents on the control software and the app to ensure a strong future market share.

**Technological Trends and Conferences**

The transportation sector has been under constant development. The electrification of all the transport sector is set to continue [2] as it offers much more efficient and emission neutral conditions. Along with smaller more mobile electric vehicles have gained popularity, such as the electric scooter [3]. The increased use and issues have caused some governments to ban the use of these electric systems, such as The Netherlands. However, there are motions to remove this ban due to the increase in safety and popularity of the systems.

Autonomous travel has gained popularity as the user is now able to spend the time instead of focus on driving which can be seen by the interest in the Tesla driving aids catching on. Fully autonomous systems are already being introduced to systems which require less positional guidance such as trains [4] this allows for more precisely timed systems, elimination of human error and lower operation costs.

Users using smaller forms of transportation are often plagued with the annoyance of being exposed to the weather this is because the protection is often sacrificed for mobility and size. Compact weather protection is however becoming more common as the users want the luxury of larger transport with the ease of use of small mobile transportation. This can be seen with the increase I use of mobility scooters and their weather protection [5].

Due to Covid-19 many conferences are cancelled or have been moved to inline. The conferences such as the “Re-imagine Mobility in the Digital Age beyond Covid-19” [6] mainly focus on the large scale transport. A common thought is that modern transport should have three common factors: electric, shared, and autonomous. The belief is that these three factors will make travel more efficient, lower cost and with fewer emissions. Personal modes of transportation will seas to exist in the future; sharing transport allows for use only when needed. The autonomous e-scooter shares all the three main principles as it is an autonomously guided electric scooter for shared use. Although focussing on larger modes of the transportation the conference does acknowledge the emergence of a smaller shared system such as the go sharing scooter [7] and Felyx scooter [8]. These offer a more convenient mode of transport in dense areas such as cities.

## 3. Business Innovation

### 3.1 Business Model Canvas

By applying the Business Model Canvas to the project, a clear foundation was laid out in order to get detailed insight on the possible different sectors that can help influence the business such as key partners, activities, and the potential customers that will be using our product. This tool can eventually help with understanding how the business can generate an income, deliver value and which areas to focus on in order to be successful.

For our thee wheeled e-scooter, the key partners that we anticipate include national transportation services, governments, enterprises, companies situated on the High Tech Campus, business parks, patent offices, rijkswaterstaat, rental scooter agencies, tour operators/agencies, and public transport operators. All those partners represent external companies/agencies that are essential for the business to flourish and expand. Since this project revolves around autonomous e-scooters, the key activities that we would be immersed in involve further app development and research, mechanical design refinement, employing charging-bay workers, urban planning of cities, and machine learning. Those key activities are certain tasks that have to be satisfied and are closely tied in with the value proposition since those key activities are the necessary steps needed to be taken to ensure that the value propositions are delivered to the consumers. Therefore, the value propositions would be ensuring that the battery is always charged and thus the consumer does not have to store the scooter themselves. In addition to that, the app must be intuitive to use, the e-scooter is eco-friendly to combat the current issue with greenhouse emissions in the transport sector, the weather protection unit is installed and functional, and autonomous delivery & take-away are maintained at all times.

Resources are needed to effectively run a business and the resources for our e-scooter come in the form of assets such as employees at the hubs (charging and maintenance), the Application and its technical infrastructure, Research and Development (R&D) centers, office workers and engineers, mobile service team, and user data/algorithms. The customer values/relationship needs to be identified to help understand how we can reel in customers and obtain a smooth interaction with them. The main selling points would be through convenience, ease of use, affordable prices, ensuring safety measures at all times, and providing comfort and weather protection. The customers themselves are easily identifiable and are divided into two types which include direct such as working class individuals, students, tourists and indirect such as enterprises, train stations, travel agencies, and park and ride (P+R). To promote our business and raise awareness of our product to acquire more customers, we can rely on channels which would be our app, through the users themselves via word of mouth, endorsements, social media platforms such as Instagram and email marketing.

After laying out most of the framework in the BMC, the cost struture which includes the costs that need to be paid out and the revenue streams which are the means that would provide us with revenue can be pinpointed. The cost structure would entail production costs, staff salaries, R&D, insurance, patents, maintenance of the app and general e-scooter maintenance, hub infrastructure, software development, marketing and advertising. Finally, the revenue streams would be via memberships, pay per use which is time based and subsidy funding such as cash grants and sponsorships.

### 3.2 Market Research

In the city of Eindhoven, shared transportation has been widely implemented by Felyx and GO Sharing, with each company making 200 electric scooters available for public use. Following the adjustment period of the e-scooters to Eindhoven, complaints regarding nuisance and destruction has shown a downward trend [9] with the inhabitants of Eindhoven showing promising interest. According to GO Sharing CEO Raymond Pouwels, the company “sometimes cannot keep up with the demand” [10] and is currently asking the municipality of Eindhoven for expansion permission. However, the municipality of Eindhoven has maintained the stance of placing a maximum of 200 scooters for both Felyx and GO Sharing due to space logistics. Current users now are using the shared e-scooters more than usual, as opposed to public transport due to the coronavirus pandemic, which creates a need for more public sharing transportation within the city. The country’s push towards a ban on gas- and diesel-powered vehicles within the city centres by 2030 [11] increases the feasibility of the e-scooter project as well as the reach for more potential customers in comparison to the present. Implementing the e-scooter project expands the reach of potential customers to the working class, students and tourists. Indirectly, the e-scooter caters to enterprises, train stations, travel agencies and park and ride entities as transportation alternatives with the high mobility capability that the e-scooter provides.

The target market for Eindhoven and its potential customers is large; 131.689 individuals within the age groups of 10-49 years or 155.444 between 18-64 years [12] which constitute as direct customers who live within the city. Additionally, the 61.381 daily commuters in the Central station and Strijp-S train station and the 3.434.600 annual domestic tourists [13] presents the extensive potential customers that the e-scooter can cater to. The current competitors, Felyx and GO Sharing take up a portion of these numbers, but due to its current fleet limitations, the market pool remains large. Weaknesses of these competitors can be taken advantage of, to keep the majority of the market towards the e-scooter proposal. Both companies uses Mopeds as their products, which is bulkier than the e-scooter and requires more spacing for parking and storage, subsequently why the municipality of Eindhoven has kept a 200 unit cap for the companies and this has been their biggest concerns. Evidently, complaints have been raised against these companies for nuisance and spacing. In fact, a user has received a fine for improper parking without the user's knowledge that the parking was wrong. Incidents like these reduces the confidence of users towards the competitor and this issue is addressed by the e-scooter's self-driving ability to drive back to the hub. Pricing wise, Felyx charges a flat rate of €0,30/m of usage and €0,10/m of parking whereas GOSharing offers dynamic packages depending on the user's frequency of use. For comparison, the flat rate fees are €0,29/m of usage and €0,05/m of parking. Felyx argues that the higher rates are due to their products made with higher quality, making it more stable, comfortable and safer. The success of Felyx within Eindhoven reflects the price compromise the customers are making for comfort and opens the possibilities that the customers are willing to compromise for pricing. The e-scooter project can take advantage of the present pricing schemes by introducing convenience – parking convenience and the peace of mind that fines from improper parking is non-existent.

### 3.3 Company Research

We-all-Wheel is a company that has seen this problem and will come up with a solution. They believe that transportation to work or school, for example, can become fun again by introducing innovation and variation. The era in which everyone comes to work by car and is stuck in traffic jams every day is over and has to make way for a time with a huge range of different transport options. In a conversation with Jacoba van Gastel, founder of We-All-Wheel, she said she believes that people can get to their destination much faster by using other means of transport than cars. [14] Going to work by bus and using an e-scooter one day for the last mile and going on foot the next day will keep you enjoying your journey and, at the same time, make room on the road for car users which will reduce traffic jams. Van Gastel creates awareness in society by introducing as many people as possible to all the innovative means of transport, such as her own Iwheel e-scooter, that are on the market today. In this way she contributes to a better way of transportation in the future.
Van Gastel works together with Sandra Hueber, director of Brightup , a company that is committed to making the world a bit more enjoyable, liveable and sustainable. They do this by stimulating the use of bicycles and similar means of transportation. Hueber once went through a project with bicycles equipped with GPS. This GPS signal was particularly difficult to follow in densely built-up areas and could sometimes disappear completely from the radar. She therefore tipped to never fully rely on GPS when you are trying to find your way autonomously.

## 4. Conclusion and Recommendations

The Triz methodology provides the solutions for the required conditions for autonomy. The tool focuses on the parameters of device complexity and extent of automation; automating the scooter requires software algorithms and mechanical systems for balance. This in turn increases the complexity of the device. Inventive principles of feedback (as research) and replacing the mechanical system provide the solution for the parameters selected. The design provides a good foundation for integrated application use as well.

The market research shows a high feasibility for implementing the e-scooters for Eindhoven. The large market and far-reaching potential customers as well provides the necessary growing market to address. The competitors in Eindhoven are currently capped with its number of units and is not in the position to take advantage of the large market. Moreover, the research indicates competitor weaknesses that the e-scooter can take advantage of for competition.

Further research/investigation into legality is required to bring the product into the market. The application of automation as well the E-scooter restrictions must be upheld once legalized (in the future). The software and app design will concern the majority of these restrictions which can be submitted for a patent to ensure ownership of the product and market share. Following future technology trends, company collaborations and conferences will allow and aid in the understanding of changing restrictions and the growing autonomous and electronic drive markets which is useful for further developments.

## 5. Literature

Bibliography

[1] F. O'Sullivan, „Paris Has a Plan to Keep Cars Out After Lockdown," Bloomberg CityLab, 29 April 2020. [Online]. Available: https://www.bloomberg.com/news/articles/2020-04-29/paris-has-a-plan-to-keep-cars-out-after-lockdown. [Zugriff am 2020].

[2] S. Descant, „The Electrification of Transportation Trend to Continue," Government Technology, 2 January 2020. [Online]. Available: https://www.govtech.com/transportation/The-Electrification-of-Transportation-Trend-to-Continue.html. [Zugriff am September 2020].

[3] H. Leon, „E-scooters Have Doubled in Popularity and Tripled in Injuries," Observer, 1 October 2020. [Online]. Available: https://observer.com/2020/01/e-scooters-popularity-injuries-us-millennials/. [Zugriff am December 2020].

[4] D. Briginshaw, „Rail is on the way to autonomous trains," International Railway Journal, 1 August 2019. [Online]. Available: https://www.railjournal.com/opinion/rail-autonomous-trains. [Zugriff am October 2020].

[5] W. Harrison, „Rain Protection Accessories for You and Your Mobility Scooter," CareCo, 26 September 2019. [Online]. Available: https://www.careco.co.uk/blog/rain-protection-accessories-mobility-scooter/.

[6] „Re-imagine Mobility in the Digital Age beyond Covid-19," Smart Mobility Conference, 5-7 October 2020. [Online]. Available: https://smartmobilityconference.com/. [Zugriff am 5-7 October 2020].

[7] „Stap op en Go," GO Sharing, 2020. [Online]. Available: https://go-sharing.nl/. [Zugriff am 2020].

[8] „Felyx is a fast, convenient and sustainable way to move through the city," Felyx, 2020. [Online]. Available: https://felyx.com/. [Zugriff am 2020].

[9] B. Hoffman, „Less and less complaints about green scooters in Eindhoven, Helmond is also positive," 13 May 2020. [Online]. Available: https://www.ed.nl/helmond/steeds-minder-klachten-over-groene-scooters-in-eindhoven-ook-helmond-is-positief~a489128c/. [Zugriff am 6 January 2021].

[10] R. Burg, „Eindhoven is overrun by green shared scooters," 25 September 2020. [Online]. Available: https://www.ed.nl/eindhoven/eindhoven-wordt-overspoeld-door-groene-deelscooters~a3d298f0/?referrer=https%3A%2F%2Fwww.google.com%2F. [Zugriff am 6 January 2021].

[11] F. O'Sullivan, 7 October 2019. [Online]. Available: https://www.bloomberg.com/news/articles/2019-10-07/how-amsterdam-is-closing-the-door-on-downtown-cars. [Zugriff am 7 January 2021].

[12] CityPopulation, „Eindhoven," January 2020. [Online]. Available: https://www.citypopulation.de/en/netherlands/admin/noord_brabant/0772__eindhoven/. [Zugriff am 7 January 2021].

[13] „Facts and Figures Eindhoven 2015," 2015. [Online]. Available: https://www.eindhoven365.nl/_asset/_public/Facts-Figures-Eindhoven-2015-EN.pdf. [Zugriff am 7 January 2021].

[14] We all Wheel, 2021. [Online]. Available: https://we-all-wheel.com/. [Zugriff am 7 January 2021].

[15] J. Salt, „RC Servos - The Muscles of Our Hobby," RC Helicopter Fun, November June 2020. [Online]. Available: https://www.rchelicopterfun.com/rc-servos.html. [Zugriff am October 2020].

[16] Brightup, 2021. [Online]. Available: https://www.brightup.nl/. [Zugriff am 7 January 2021].

# Devices to help companies execute corona policies

Sander Baijens[1], Patrick Burmester[1], Leon Schalij[1], Daan Berens[1], Mark Schoenmakers[1], Jan Dubrowitsch[2], Friedrich Welt[2], Johannes Gerner[2], Marcel Seibold[2]

*[1]University of Applied Sciences*
*Fontys EngineeringEindhoven, Netherlands*
*[2]University of Applied Sciences*
*Technische Hochschule Ulm, Ulm, Germany*

**Abstract:** In this paper, the development process of a device which helps companies to execute corona policies is covered. First, a suitable project is chosen from a series of concepts. When specific requirements are set for each module, the final designs and will be discussed.

**Keywords:** Corona, device, invention

## 1. Introduction

The group which worked on this project consists of Dutch students from the Fontys university in Eindhoven and students from the University of Ulm. They are all in the last year of their mechanical or mechatronics engineering studies.

This document will provide information about our process and goals in developing a machine which can collect, clean, and dispense reusable face masks.

### 1.1 Project assignment

The goal of this project is to invent and design a device which helps companies adhere to corona policies. This is done in collaboration between a group of five students from the Netherlands, and a group of four mechanical engineering students from Germany. The Dutch project group consists of two mechatronic students, and three mechanical engineering students.
In this report, the method of decision making will be thoroughly explained, while exploring different concepts. When a concept has been chosen to develop, specific requirements will be set for each subsystem. During the designing process, these requirements will be implemented and verified.

### 1.2 International collaboration

As said before, the Dutch students will work together with a group of German students. The relationship between the two groups is customer-client like, with the Dutch group being the customers. They will provide a specific task for the German students and hold weekly meetings to check on progress.

## 2. Project Concepts

Since the assignment was very unspecific; ‘Device to help companies execute corona policies’.
The group needed to decide on which exact problem they wanted to solve. For this, research has been done for several project concepts. Some of the more promising concepts were:

- Device which makes an automatic closing door (spring driven) also automatically opening, so there is no need to touch the door;
- Portable air cleaning system to filter out the Coronavirus aerosols;
- Device to collect, clean and dispense reusable masks.

The waste which is produced nowadays during this pandemic is tremendous. Recent studies claim that since the start of the pandemic last year, more than 1.5 billion disposable face masks ended up in the oceans. Right now, there are even more disposable face in the oceans than jellyfish.
The group decided that this was and will be a big problem in the near future, and therefore decided to go through with the last project concept.

## 3. Reusable face mask machine

The machine that has been chosen to develop this project is a reusable face mask machine.

### 3.1 Problem definition

The use of disposable face masks results in a lot of waste, as previously stated. Therefore, the use of reusable face masks needs to be encouraged. If a company provides these reusable face masks their employees will use these instead of disposable face masks. Therefore, a machine has to be developed to automatically collect, clean and dispense these reusable face masks.

### 3.2 Project goal

The goal of this project is to design a fully automated vending machine, which will make sure that employees of a company can make use of reusable face masks instead of disposable ones.

## 4. Requirements

In order to keep track of the end goal of the system, concrete requirements must be set up for each subsystem of the machine. These requirements are each assigned one of the following three properties:

[M] Must-have: Non-negotiable product needs that are mandatory for the team.

[S] Should-have: Important initiatives that are not vital but add significant value.

[C] Could-have: Nice to have initiatives that will have a small impact if left out.

### 4.1 Collection Module

**User requirements**

- R01 (M) Collection Cycle time must be short enough to avoid a long waiting time for the user;
- R02 (M) Collection of masks must be done without having to touch the machine;
- R03 (M) The device must protect against injury of the user;
- R04 (S) The device shall provide hand sanitizer for user after using the mask;
- R05 (S) The device shall use reasonable ergonomics;

- R06 (M) The device must indicate that it is function and it must be intuitive to use;
- R07 (M) The device must indicate if it is full when the cleaning module or the garbage bin is full;
- R08 (M) The device must be noticeable;
- R09 (M) The device must be easy to set up.

**Technical Requirements**

- R10 (M) The device must be built to accept a specific masks type.
- R11 (M) It must reject or sort out unknown masks and other objects, which do not belong to the system;
- R12 (M) The device must not damage the masks while collection or handling.
- R13 (M) The device must prepare the masks for cleaning, bring the masks in the right position;
- R14 (M) Must prevent spreading of dust/bacteria/fungi/etc inside the machine;
- R15 (S) The design shall take ease of maintenance into account;
- R16 (M) The electrical components must run on 230V;
- R17 (M) The device must comply with the necessary standards and laws;
- R18 (M) The device must handle the masks smoothly and prevent blockages in the system.

### 4.2 Cleaning Module

- [M-3-1] The masks need to be completely disinfected;
- [M-3-2] The masks need to be dry;
- [M-3-3] Must prepare for dispensing the masks;
- [M-3-4] This module must be insulated to prevent water damage to surrounding electronics;
- [M-3-5] Module must fit in 83x83x100 cm;
- [M-3-6] The masks will be transported between two conveyor belts;
- [S-3-1] The masks need to be visually clean (no stains);
- [S-3-2] Easy accessibility;
- [S-3-3] The masks can be washed entirely while being transported.

### 4.3 Dispense Module

- [M-1-1] The module must dispense the masks hands free;
- [M-1-2] The module must output a single mask per dispense cycle;
- [M-1-3] The module may not take longer than 2 seconds to dispense one mask;
- [M-1-4] The module must include the transportation of masks from the cleaning module to the storage of the dispenser module;
- [M-1-5] The module must protect the masks from contamination during storage and dispense;
- [M-1-6] The module must allow for compliance with mask guidelines:(https://www.government.nl/binaries/government/documents/leaflets/2020/07/10/leaflet-how-do-i-use-a-non-medical-face-mask/Leaflet-How+do+I+use+a+non-medical+face+mask.pdf) ;
- [S-1-1] There is a designated space for clean masks to be stored;
- [S-1-2] The module has a function to count the masks available in the storage;
- [C-1-1] Dispensed masks are wrinkle free.

## 5. Final design

In this chapter, the final design of all three modules and the entire final assembly will be shown and explained.

### 5.1 Collection module

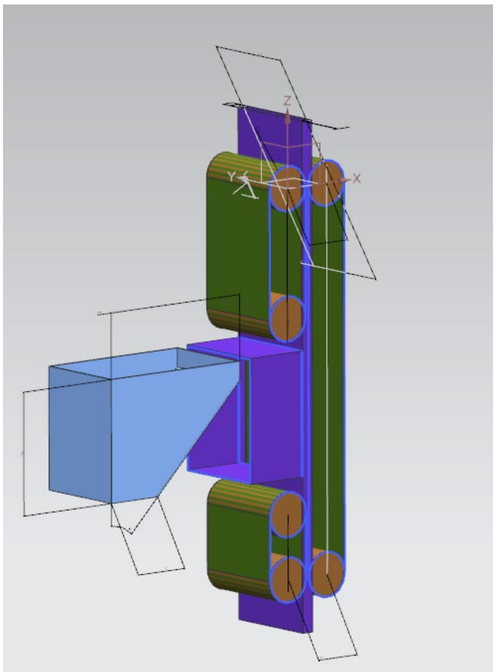


Figure 1: NX model of collection module

The final design of the collection module allows for the user to enter the face mask in a small opening. This opening is just big enough for a facemask and leads to a vertical vent (dark blue). The vent contains a sensor to determine the validity of the facemask. If the face mask is classified as too old, or nothing is sensed, the basket (light blue) will be inserted into an opening in the vent, guiding the inserted objects to a trash bin. The facemasks will be guided with the use of a spring-loaded conveyor belt (green). With this method, it is prevented that face masks get stuck in the vents. Since there is no need for a latch, users of the machine have no risk of getting their fingers between components. Even if a user tries to push their hand inside the vents, the spring loading of the conveyor belts prevents the user from injury.

### 5.2 Cleaning module

In this module the collected masks are going to be cleaned; cleaned in this will mean 'corona-free'. There are some different methods for disinfecting an object which has been in contact with coronavirus particles. Unfortunately, none of these methods are approved by science to be 100% effective. This is mainly due to the newness of this virus; no research can prove 100% disinfection with a certain method. With this knowledge, we chose to adapt a steam blaster in our cleaning module. This method relies on killing the virus with heat from vaporized water. This results in the most efficient way of cleaning these objects. The conveyor belts will be belts with little openings in them, a mesh structure. This way we can transport our masks through a beam of steam, which heat will kill the coronavirus particles. Since this method is not approved yet, the cleaning model will be represented as a 'black box' in the design, it is possible this will change in the future.

### 5.3 Dispense module

This module represents the final stage of the face mask. This module includes a transportation system from the cleaning module, a storage for the cleaned masks and a mechanism to dispense one mask to a customer.
The transportation will be done by a set of conveyor belts, as seen in the picture below. In the top of this picture the mask will be turned 90 degrees to fit nicely into our storage system, this can be seen in the last chapter.

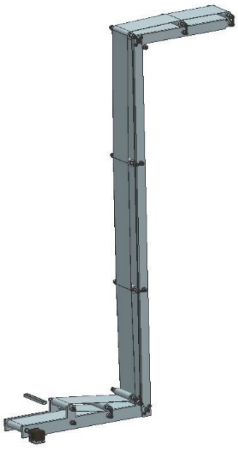


Figure 2: NX model of transportation system

The storage system contains of a slide, where 10 masks can be stored at the same time. This storage system mainly works with gravity, every mask slides to another mask. Below the storage system is displayed.

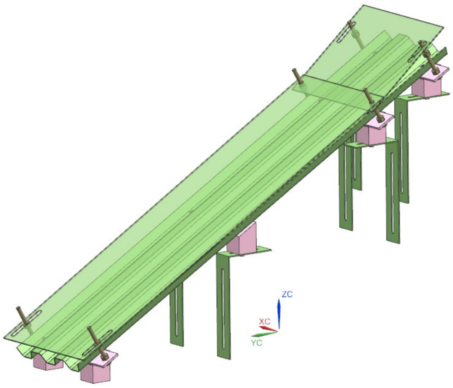


Figure 3: NX model of storage system

If a customer wants to get a mask, he simply draws his hand before the proximity sensor which is mounted at the front of the machine. Then the last conveyor belt starts to move just enough to supply one face mask into the dispense brackets.

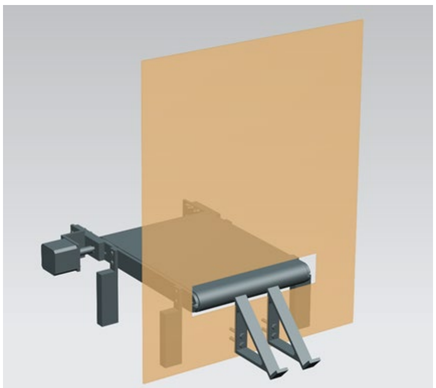


Figure 4: NX model of dispense module

## 6. Assembly of all modules

In the picture below, all modules have been assembled together and mounted inside a framework. This framework is designed in a way that it can fit through a normal door.

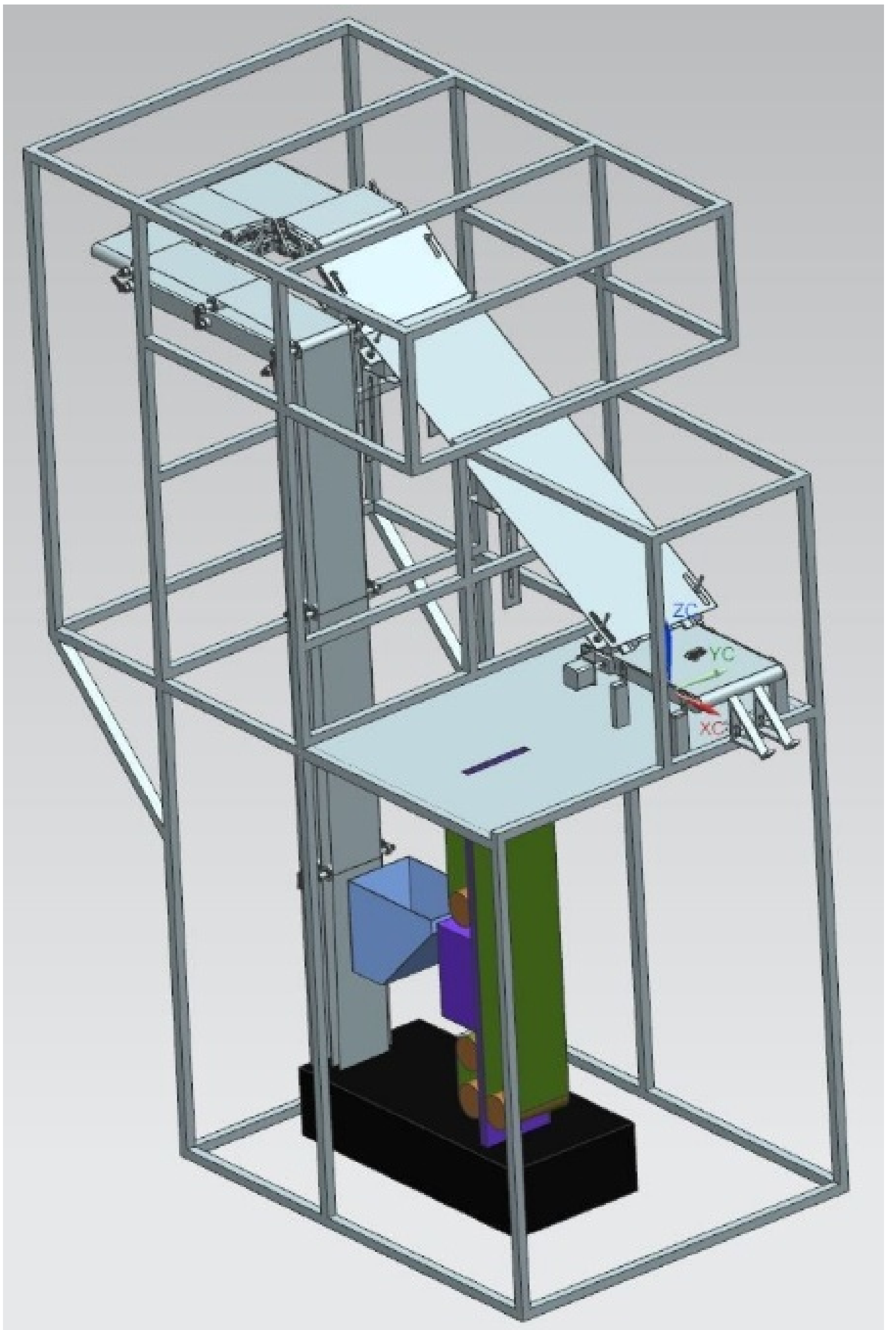



Figure 5: NX model of full assembly

## Acknowledgments

We would like to thank both our universities and especially our tutors, Geert-Jan Evers and Mr. Watty for their support and guidance in this project.

# Dynamic microplastic filter

Maurice Coolen, Marco van Gerwen, Hidde Schot, Mateusz Szyłak, Etiën Tax

Fontys university of applied sciences, School of Engineering, Eindhoven

h.schot@student.fontys.nl

**Abstract:**
It is almost impossible to imagine world without plastic. In present times it is used in almost every branch of our daily lives as well as in different branches of industry. Unfortunately, plastic particles can take even up to thousand years to fully decompose. During the process of degradation small parts of plastic, called microplastics get carried away and end up in the water, soil or even inside animals. The question arose, whether it is possible to reduce the amount of microplastics that ends up in the main water bodies like rivers and lakes. There are already systems installed in water treatment facilities that trap microplastic by use of sand. However, there is no method developed that is able to clean the plastic particles from the sand. Therefore, it was decided that there is a need for solution that will be able to cleanse the water from microplastics without using additional medium. It was important to address this issue because many might not notice the problem of microplastics which ends up in our water and food. In order to determine the best possible solution TRIZ method was used which is often applied for innovative solutions. Main findings of the research allowed to determine best answer to the given problem which was the use of cross flow filtration system with dynamic membrane filter. The system consists of automated cleaning station which allows for the continuous water flow without the need of stopping entire system. Developed system still has to be experimentally tested in order to determine true efficiency of the product.

**Keywords:**
Microplastics, Dynamic membrane filter, Water treatment facility, Water cleaning

## 1. Introduction

This project was carried out based on the information supplied by the Dutch water treatment facility (Waterschappen) and general research taken from relevant sources online [1]. Important objectives of this project make the solution affordable, recyclable, and environmentally friendly. A lot of benefits are won since two schools are cooperating with each other. The University of Vienna and Fontys Hogeschool Eindhoven worked together to make sure this project will be finished with a clear conclusion and recommendations.
Obtained research has shown that there is a serious need for a solution that is going to filter the water from the non-organic particles [2]. In this case the focus was put on the particles of plastic, called microplastics. Current systems that are installed in the water or water treatment facilities do not filter out this part of pollution. In oceans and rivers only, big pieces [1] are filtered out, and at Waterschappen microplastics are removed from the water with sludge which is later used to fertilize the fields. Because of that principle it goes back to groundwater and later into the water streams that end up in rivers, lakes, and oceans.
This research and prototype creation being important to further understand the process of microplastics filtering. The goal of this project is to develop a solution that could be implemented in any water treatment facility in order to clean water from microplastics. This paper was written because plastic pollution is one of the biggest problems in terms of Earth pollution [2]. Creating the prototype

and further understanding the subject will help the microplastic removal and will contribute to the cleaner future. Following the research question of: *How can microplastics be most effectively prevented from entering natural water bodies like rivers and lakes in a cost-effective way?*

## 2. Background

During the project, a couple of design tools have been implemented in order to come up with the best possible solution and answer to the research question. Starting with a functional analysis that breaks down the general description of the invention into main and sub functions which is useful for complete understanding of how the invention should work and what concepts could be useful to implement. The process of concept generation started with literature research to find the current technological trends and findings regarding the filtration methods used in Waste Water Treatment Plants (WWTP's) to filter out Microplastics (MP's).

A study [1] has shown that there are many filtration methods available of which the most promising ones have a removal efficiency of up to 99%. The most promising methods include the Membrane bioreactor (MBR) and Dynamic Membrane (DM). These methods were further analyzed to find the best possible solution for an effective implementation in WWTP's

The Membrane bioreactor method replaces the conventional filtration method that is currently used in most WWTP's and is therefore not easily implementable because of the high upfront investments. It partly works just like the Conventional Activated Process that is generally used in wastewater treatment plants, but it integrates a selective membrane in the form of microfiltration or ultrafiltration which rejects the solid materials that are developed by the biological process that takes place. The MBR method is seen as the most effective way to remove microplastics in WWTP's. However, the necessary high capital investments, maintenance costs, potential membrane fouling and the need for regular chemical cleanings [3] make this method not ideal for the solution that is sought after.

The Dynamic Membrane method uses a membrane type filter that consists of several layers, including a secondary membrane that lies on top of a supporting membrane. The supporting layer is usually made out of stainless steel, ceramic or woven fabric. This layer form the foundation of the secondary membrane. On top of the supporting layer, a deposited layer that acts as the main functioning part of the filter. This secondary membrane is formed by deposition of suspended solids that are present in the water that is to be filtered, which makes this membrane self-forming. There are typical forces which makes the interaction between formation material and supporting membrane possible, these include: electrostatic interactions, van der Waals interactions, hydrophobic interactions and steric interactions. [4] The particles of the secondary membrane have a larger size than the pores of the support membrane and are able to catch the microplastics. The main downside of this method is the potential clogging of the membranes [4].

While choosing the filtration concept based on literature and the design requirements. TRIZ was introduced to find solution for weak points in the different methods using contradictions. Also, the ideality theory has had a massive impact on deciding the filtration method for the invention, as the final solution is a self-forming filter, which was the closest the team could realistically get to the ideal of self-filtering water. In the end the decision was made to apply the Dynamic Filter method. A morphological chart was then implemented with the main functions from the functional analysis to generate more detailed concepts based on the DM filter. These concepts were graded based certain criteria stemming from the requirements. And the best performing concept on all criteria was chosen. In the process, results from patent research has helped to find an innovative solution by carefully selecting existing technologies that have been patented [5] recently.

Since the DM method can be used as a final step in any WWTP and is not necessarily an expensive solution this is the ideal method that is to be implemented in the new product. However, it is important to find a low cost cleaning solution to reduce the maintenance costs in order to be able to provide a cost-effective solution. Just as there are several possible filtration methods, there are also many different membrane cleaning solutions available. These include simple brushing but also more complex

cleaning methods such as backwashing with water, air or a mix of these two. Learning from the problem that is occurring early on in WWTP process where microplastics are being removed from the water but mixed with the sludge, making it impossible to recycle or even prevent it from re-entering nature [6]. Therefore a solution must be found which does not allow any other media to mix with the filtered microplastics so that these can be contained and dealt with effectively.
Backwashing uses pulses of either water, air or both in the opposite direction of the waterflow. This method will break the contaminants and parts of the secondary membrane free from the support membrane. The contaminants must then be removed to regain the optimal flow which is intended for the filter. Taking all possible cleaning solutions into consideration, it was decided to use air backwashing in combination with brushing as there was little proof to be found that air backwashing on it's would be sufficient. The addition of brushing increases the cleaning capabilities while barely increasing the cost. This solution also has the benefit of using air instead of water so that only MP particles are considered as final residue.

## 3. Results

All the previous work done leads up to a design that can be implemented in existing water treatment facilities. This is a design based on filters that in flat sheet will be 1 by 1 meter. This leads through calculations to a basic dimension that might not suit every water treatment facility but it is just to show the design for a specified water treatment facility.
Filtering system has to be able to filter 8000 m3/h.

$$Q = \frac{\mathrm{V}}{\mathrm{t}} = 8000\,\frac{\mathrm{m^3}}{\mathrm{h}} = \frac{2.22\ \mathrm{m^3}}{\mathrm{s}} \qquad \text{Eq. 1}$$

$$2\pi\mathrm{r} = 1\mathrm{m}\,, \mathrm{r} = 0.159\mathrm{m} \qquad \text{Eq. 2}$$

$$Ao = \pi\mathrm{r}^2 = \pi \times 0.159^2 = 0.0794\mathrm{m}^2 \qquad \text{Eq. 3}$$

$$V = \frac{\mathrm{Q}}{\mathrm{A}} = \frac{27.95\mathrm{m}}{\mathrm{s}} \qquad \text{Eq. 4}$$

Knowing that there is 0.08[mm] of space between each wire in mesh, area of the singular filtering square can be determined.

$$Asmall = 0.08 \times 0.08 = 0.0064\mathrm{mm}^2 \qquad \text{Eq. 5}$$

Next, area of the filtering square including the wires surrounding singular filtering square. Knowing that wire has a thickness of 0.05[mm] calculations are as follows.

$$Aboundar\mathrm{ie} = 0.13 \times 0.13 = 0.0169\mathrm{mm}^2 \qquad \text{Eq. 6}$$

$$Atotal = 1000000\mathrm{mm}^2 \qquad \text{Eq. 7}$$

With this information it is possible to determine the number of filtering squares inside the filter and effective filtering area.

$$An = \frac{\mathrm{Atotal}}{\mathrm{Aboundarie}} = 59171597 \qquad \text{Eq. 8}$$

$$Aeffective = \mathrm{An} \times \mathrm{Asmall} = 0.3787\mathrm{m}^2 \qquad \text{Eq. 9}$$

$$\text{Cross flow velocity} = \frac{Q}{Aeffective} = \frac{5.862m}{s} \qquad \text{Eq. 10}$$

In order to have a continuous flow through the filters instead of having to stop the filtration process to clean a filter a new system is designed. This systems divides the water flow over 7 dynamic membrane filters. These filters are arranged in a circle and can be changed to get cleaned. The complete system can be seen in Figure 2. The top part consists of 7 filter housings and a cleaning station. The housings will contain the filters (Figure 1) inside of them. Pipes will lead to the housings and the water will flow through the filters. The filters consist out of three parts, the bottom metal plate, a rubber to seal off the electromagnet from water in the housing and the filter mesh itself. Each housing contains a solenoid valve on the bottom and a pressure sensor on the top pipe, this can be seen in Figure 3.The top pipe will have a free flow into the big central pipe, this should be the clean water. The water will flow to the top so there can also be a little bit of sedimentation in the filter housing this should leave some more particles behind which can be cleaned away after the filter is out. Once the pressure inside the filter housing gets too high the flow to the filter will be cut off and the solenoid valve will open. This releases the standing water in the housing. After that the filter will be released by cutting of an electromagnet in the bottom of the filter housing. Then the filter will drop into the wheel at the bottom via a pneumatic cylinder. A cutout of this can be seen in Figure 2.The wheel will spin and a second pneumatic cylinder will stand ready to place a new filter in the housing. The clogged filter will be moved to the cleaning station. The cleaning station is a pipe, different from the filter housing, in the top of the system. In this pipe the filter will be back pulsed with air and brushed on the inside and outside. This should remove all the microplastics from the filter. Once the filter is clean it will be stored in the wheel until another filter is clogged and then the process will repeat itself. The microplastics will be blown through a pipe and will be caught in a container. This should make the microplastics ready to be processed in a waste treatment facility.
Most of the structure will be made out of Stainless steel type 316. This material is best resistant against moist environments and is also nonmagnetic which helps the filter changing. It is widely used and it is easily available. Stainless steel type 316 can also be recycled thus making the largest part of the structure sustainable.

*Figure 12 Filter changing mechanism*

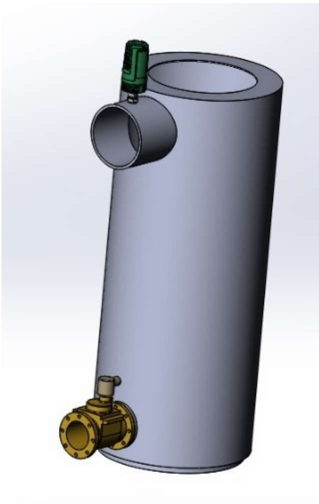


*Figure 1 Filter housing with pressure sensor (top) and solenoid valve (bottom)*

*Figure 11 Dynami membrane filter*

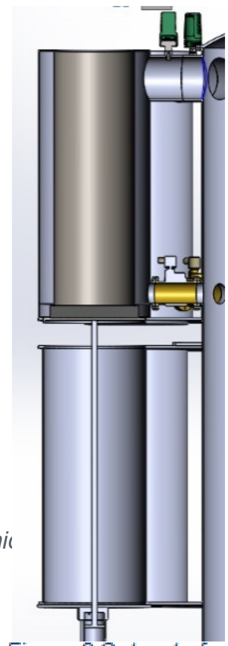


*Figure 2 Cut-out of system*

## 4. From innovation to start-up

Research of macro environment shows that microplastics are gaining more attention. Studies show that microplastics are everywhere, from the top of the mount Everest to the bodies of unborn babies. The Netherlands will be the first country where the dynamic microplastics filter will be used. Since the Dutch government already acknowledged the problem, they will be one of our key partners. With subsidiaries from the government and experts from wastewater treatment facilities, like Waterschappen, the start-up company will be able to build and test the innovation properly. The goal is start selling to waste water treatment facilities and potentially large companies that produce a lot of wastewater. Microplastics also are not just a problem in the Netherlands, so the next step would be to start selling the product to the same type of companies in different countries. The way the dynamic membrane filter offers value to the costumer is by reducing their waste which helps their company brand. Those companies could show their eco-friendliness with a sticker that resembles the green energy sticker only now for plastic waste. The system can also be modified to fit customer needs. They can add or remove filter cylinders based on the capacity their facility can handle. The product will be a large investment for those companies, the current estimate for the product price right now would be somewhere between 7.500 and 12.500 euro. This number is an extremely rough estimate, based on the size of the product, the materials, electronics, and workforce needed to build a complete system. This estimate is prone to change once the first tests with the prototype have been conducted.

## 5. Conclusions and recommendations

On the start of this project research questions was formulated. How can microplastics be most effectively prevented from entering natural water bodies like rivers and lakes in a cost-effective way? The goal was to find the best possible solution to overcome this problem. There were many possible solutions for this task but through research it was possible to eliminate some of them, so that only the best ones were left. From all the research conducted, including calculations, it can be concluded that the best solution for preventing microplastics to enter rivers and lakes is use of dynamic membrane filtration system in a cross flow configuration. The system itself should be installed as the last process of water cleansing in water treatment facility. This way it can be assured that filter will work longer as it will not clog with other particles present in the water. It is recommended to test the setup in order to confirm all the theoretical research that was conducted and to validate the efficiency of the system. It is important to check if the system will be able to satisfy the required water flow by use of gravity or there will be a need of installing water pump. Next step would be to check for how fast the filter is able to rebuild the dynamic membrane after cleaning. Also during the cleaning process it has to be checked if the air pressure used for the back pulsing is strong enough to release the microplastics from the filter mesh. There might be a need to add special additive after cleaning in order to help with the coagulation process. For the future researchers about this subject it is recommended to focus on finding a new method to remove microplastics from the water in the earlier processes as the amount of microplastics in those stages is much higher. Finding such a method would result in a serious improvement of water without microplastic in it.

## 6. Literature


[1] L. Hou, D. Kumar en C. Geun Yoo, „Conversion and removal strategies for microplastics in wastewater treatment plants and landfills," *Chemical Engineering Journal,* 2020.

[2] L. C. M. L. H. S. C. M. T. C. J. M. J. C. B. Marcus Eriksen, Plastic poluttion of the world's oceans: More than 5 trillion plastic pieces weighing over 250000 tons afloat at sea, 2014.

[3] K. Gurung, M. Chaker Ncibi en Silanpää., „Assessing membrane fouling and the performance of pilot-scale membrane bioreaction (MBR) to treat real municipal wastewater during winter season in Nordic regions.," *Science of the Total Environment ,* nr. 597, 2017.

[4] M. Evren Ersahin, H. Ozgun en R. Dereli, „A review on dynamic membrane filtration: Materials, applications and future perspectives," *Bioresource Technology,* nr. 122, 2012.

[5] D. Richards, H. Ingchen en Z. Ludak, „HIGH VELOCITY CROSS FLOW DYNAMIC MEMBRANE FILTER". USA Patent WO2020123939, 18 June 2020.

[6] C. Rolsky, V. Kelkar en E. Driver, „Municipal sewage sludge as a source of microplastics in the environment," *Current Opinion in Environmental Science & Health,* nr. 14, 2020.

[7] P. Masia, D. Sol en A. Ardura, „Bioremediation as a promising strategy for microplastic removal in wastewater treatment plants," *Marine Pollution Bulletin,* nr. 156, 2020.

# Self-Cooling Drinking System

Pascal Muskee, Pascal Vernooij, Menno Theunissen, Ricky Tailly & Thomas van der Sterren

Fontys
Hogescholen
Eindhoven, the
Netherlands

Nemanja Adzic, Muhittin Akin, Michael Boldt, Andreas Breineßl, Lukas Eisenhut, Philip Eisner,
Rychetsky Maximillian

UAS
Technikum
Vienna Vienna,
Austria

**Abstract**
This paper examines the development of a self-cooling system in collaboration with students from Fontys University of Applied Sciences and the Technical University of Vienna. This project has been targeting the healthcare system to improve the working condition of healthcare personnel, which work long hour shifts. In these shifts the personnel has to cope with fatigue, drop in concentration, and dehydration. Therefore, a self-cooling drinking system was developed to prevent the target group from experiencing dehydration. As hydration is a very important factor for blood circulation which brings concentration, this product could be of a great solution to solve this problem.

**Keywords:** Innovation, Healthcare, Self-Cooling, and Endothermic Chemical Reaction.

## 1. INTRODUCTION

### Research question

Innovation these days has become very important to the society and it is always improving in terms of technology and ideation. In this technological and sophisticated world, the importance of innovation is precious because the ideas behind it allow the society to advance and move forward. Since the global Covid-19 pandemic started, innovation has provided methods and concepts to keep performing and working during this pandemic, while protecting the society and taking more precautions to reduce spreading Covid-19.
During this challenge, healthcare workers sometimes have to work shifts of more than 4 hours. During these shifts they are wearing protective suits, to protect them from getting infected. These suits have their advantages but also some disadvantages. The important advantage is that they have low risks of getting infected. One disadvantage of the suits is that the healthcare workers cannot hydrate themselves as the suit is fully closed and they are only allowed to drink or eat on break times, which is not very often.
That is why this project is about bringing a contribution to these healthcare doctors by creating a self- cooling drinking system within a surgeon's suit. That way, he or she can always stay hydrated just

by drinking cooled water through their suits. This will help them to stay focused, be more effective and sharp. This self-cooling drinking system will specially be for doctors but can also be used by anyone who thinks that the product can bring contribution to their performance at work, at home or during their everyday life. [1]
This project will answer the follow research question; “How can the design and implementation of a self-cooling drinking system be useful to healthcare workers?”

### Problem definition

This question leads to the following problem definition of this project: Healthcare workers, mainly surgeons, nurses and those who have close contact with patients infected with Covid-19 having insufficient hydration accessibility during their shifts.
As these workers are fully protected, it takes more than 3 minutes for them to remove their suits, if they want to hydrate themselves before going back to work. Hence they sometimes skip their drinks and prefer to wait for their break time. However, it is not good for their stamina and concentration to be dehydrated. This causes a lack of concentration, low stamina and affects their ability to perform with effectiveness and reliability on patients. [2]

## 2. BACKGROUND

The background of this project brings to a multi-disciplined project collaboration of Fontys Engineering Eindhoven and the Technical University of Vienna. There will be a collaboration between Engineering students of the Fontys and Business Engineering students from Vienna. This means that both teams have different responsibilities within their disciplines. The reason for this division is to let each individual excel in their discipline. To reach the goal of the project, studying, researching, and designing the current needs will be done with the contribution of the Technical University in Vienna. Reason being for this project is because since there is always ideas to facilitate a problem, it is also possible to facilitate the life of healthcare workers by innovating and ease the use of these workers. Combining Business and Engineering will allow the project to dig into a larger perspective of how to design and implement such a product for the chosen target group.

### Overheating

One of the problems that can occur with healthcare workers that are in a protective suit for a long period is overheating and dehydration. There are few consequences of these effects. At the beginning of these problems the skin’s blood vessels starts dilating and blood will rush up into them. The next stage is sweating, which means that droplets of water mixed with all kind of minerals are leaving the body. After a while the skin is drying up because the body can’t release more water. This leads to thinker blood and so less blood is being pumped up to your head [3]. Hyperthermic could occur which means a person could get woozy, nauseous and dizziness. Because these effects cost extra energy, an intensive care worker will be exhausted earlier. This leads to negative effects on the concentration as well as the recovery time after an intensive work session. This means that overheating and dehydrations have negative effects on the work performance. This project could reduce these effects which leads to a better working performance of the intensive care workers.

## 3. METHODOLOGY

As a starting point for developing the product, some brainstorm methods were used to find ideas and concept before tackling the introduction of the project. The methodology within this project explains and describes a system of techniques used to clarify certain aspects and the approach taken in this project. For a better perspective of what kind of concepts and what requirements are taken into account, this project used the Kroonenberg Method. Method used to distinguish different concepts of ideas for the self-cooling drinking system.

## Kroonenberg Method

The Kroonenberg method was used in order to have a better idea of the best choices to be taken into account for the self-cooling drinking system. The reason behind why this method was chosen was mostly because of the specific requirements that the functions of the project needed to have. Therefore, to make the best choices, this method was used to create a better comparison schema with regards to the requirements. Scoring the requirements with a weight factor allowed concepts to show preferences. Meaning that depending on the scores received from the importance of the requirements, the concepts showed more clearance on which concept would be most applicable to the project. [4]
In order for a balanced weight factor, requirements were selected down with respect to each other. In this case, the project had 7 requirements:

- Controlling the water temperature at 15±3°C
- Keeping the cooled temperature for at least 4±1 hour
- Ability to be decontaminated
- Weighs 1±0.5kg
- Ability to be activated at a later point
- Ease of use
- Size

In the table below, these requirements were then applied for whether it could affect the rest of the requirements before the weight was calculated. The weight factor was then later on used to have the final chosen concept.

*Table 1 The requirements used for the Kroonenberg method*

| | | **Requirement** | | | | | | | **Total** | **Weight factor** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Requirement** | | A | B | C | D | E | F | G | | |
| Control the water temperature at 15±3°C | A | x | 0 | 0 | 1 | 1 | 1 | 1 | 4 | 2 |
| Keep temperature for at least 4±1 hours | B | 1 | x | 0 | 0 | 1 | 1 | 1 | 4 | 2 |
| Ability to be decontaminated | C | 1 | 1 | x | 1 | 1 | 1 | 1 | 6 | 3 |
| Weighs 1±0,5kg | D | 0 | 1 | 0 | x | 1 | 1 | 1 | 4 | 2 |
| Ability to activate at a later point | E | 0 | 0 | 0 | 0 | x | 1 | 1 | 2 | 1 |
| Ease of use | F | 0 | 0 | 0 | 0 | 0 | x | 0 | 0 | 1 |
| Size | G | 0 | 0 | 0 | 0 | 0 | 1 | x | 1 | 1 |

In terms of concepts, 4 concepts were taken into account, namely the concept 1, a Peltier module with an airgap as insulation, concept 2, Peltier module with foam as insulation, concept 3, gas expansion and finally concept 4, endothermic reaction respectively. Therefore, the weight factors were used as the product of the requirements to choose the final concept.
In order to evaluate the functionality and feasibility aspect of the design proposal, the s – diagram, also known as the Kesselring method is used for decision support of the model chosen for the design integration process.
As a result, the data from the requirements and weight factors are distributed. The minimum for the 2 segments on the Kesselring score is set on 40%. This percentage is a common percentage for the segmentation part. The two criteria combined have a minimum of 55%. Next to the minimum

percentages it is important for a concept to be in balance. For this project a significance of 10% is chosen. So the difference in the two percentages cannot be larger than 10%. As shown in figure 1, concept 4 scored the highest, then concept 2 followed by concept 1 and finally concept 3 scored the lowest. A more detailed explanation of the concepts and the reasons of their scores is explained in the next chapter.

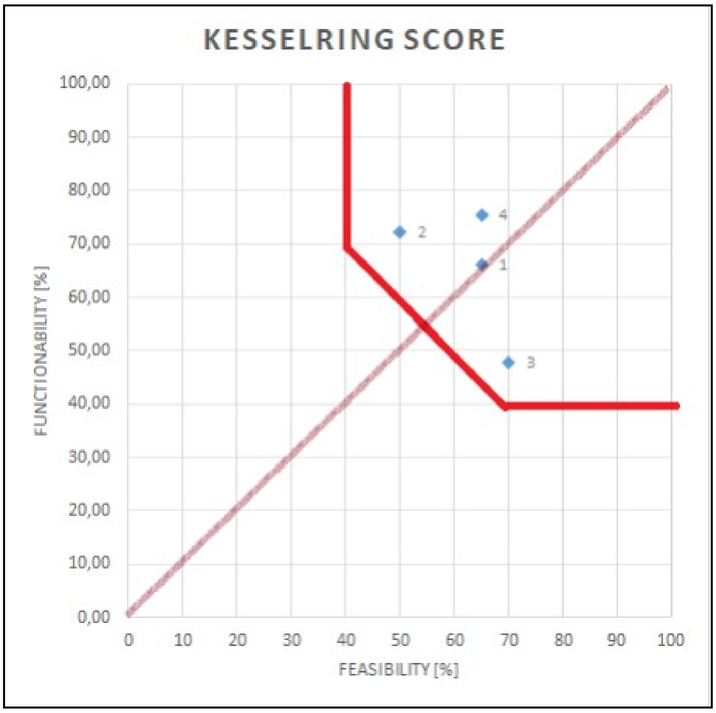



*Figure 1 The Kesselring score of the different concepts*

## 4. CONCEPT PHASE

The concepts chosen for the project were mainly based on the reliability, feasibility and accuracy in order to create a better image of what needs to be used and implemented. A morphological map was chosen as a concept of brainstorm and from that, the Kroonenberg method was used to make comparisons for choosing the best concept to work with for this project development in terms of factors of importance. The concepts are divided into 4 ideas, given complete factors for a self-cooling drinking system.

### Concept 1 – Peltier Module with an Airgap as insulator

Concept 1 comes with a very special technique: Peltier modules. The Peltier Modules are electronics systems with a top plate and a back plate, used to cool object below their ambient temperature or to maintain objects at specific temperatures using either the cooling side or the heating side. In this first concept it is important to understand that the insulator is an airgap between the thermostat and the cooling system. Considering cooling down the drink in a bottle, the concept would use the Peltier modules underneath a thermostat bottle with an airgap in between the drink and the bottle itself. The bottle would be rechargeable using replaceable batteries and would weigh about 130 grams in total with a switch and a small display On & Off. Having this concept brings advantages such as being very light and cost efficient. However, the disadvantage is that this technique is inefficient in such a small volume, which brings more heat than cooling. As the Kesselring method reflects, this concept is not as sustainable as it looks like.

### Concept 2 - Peltier Module with Foam as insulator

Concept 2 is not very different to concept 1, the only difference is the insulation, where in this case, foam was taken into account because of its ability to take any shape, unlike the airgap which has a fixed shape. The downside of using foam however is that its efficiency is dependent on the layer size, meaning that the larger the volume the better and the bottle is not very big in this case. Therefore, its feasibility is not very convenient and hence affects also the reliability of the product.

### Concept 3 – Gas Expansion

Concept 3 consists of a more mechanical approach for a cooling effect. This concept uses a bottle with foam as insulation that creates a cooling effect though a nozzle using gas expansion. This technique brings a reliable result but not efficient in terms of replacing gas cannisters every time a drink has to be cooled down. One advantage of this technique is that it brings a very suitable, cost efficient and good result. However, the downside is that there is couple of manual replacement that could be avoided.

### Concept 4 – Endothermic Reaction

Concept 4 consists of chemical reaction and trial and error experiment. In this concept, the use of a camel bag is accurate specially because of its volume and size. The technique used to cool the drink is the endothermic reaction which is a process of cooling down the surrounding as a result of absorbing energy to drop the temperature. The concept would consist of Ammonium Chloride for instant cooling, foam for insulation, and camel bag as the container.
One advantage that makes this method reliable and accurate is the fact that it is highly sensitive and flexible in crucible volume and form which makes the characteristic transition accurate. This chemical reaction consists of Ammonium Chloride which is completely safe for human consumption purposes. This concept was chosen because of its ease of use and simplicity within its accuracy. The ammonium chloride will be placed in capsules which, after being shaken, would create the endothermic reaction: instantly cooling down its surrounding. This reaction is very similar to ice packs which needs to be squeezed in order to activate instant cold pack.

## 5. ARGUMENTATION FOR CHOSEN CONCEPT

The endothermic chemical reaction was chosen to be the final concept for the self- cooling drinking system. The reasons behind the concept has to do with its feasibility, reliability and ease of use. It is very important also to take its safety into account. In this case, it was found through experiment that if the endothermic reaction was chosen, the water temperature would be able to be controlled at its 15±3°C. Also, this highly soluble reaction in water allows the cooling system to maintain the cooled temperature for a period of time, which, fits one of the requirements stated in the Methodology. As safety is very crucial when chemical reactions are being held, it was found that the use of ammonium chloride is not dangerous to the human consumption and hence in all cases would not harm anybody. Therefore, allows the ability to be decontaminated a safe requirement under control.
Another important factor is the weight, whereby this requirement does allow itself to be part of the concept. The concept weight indeed between 0.5kg and 1.5kg and hence makes it light enough to avoid being bothered by its heaviness.
Finally, the chemical reaction concept also allows the user to cool its drink at any time. Therefore, it means that the system can be activated at any time when needed. This factor allows the user to choose freely when she or he wants its drink to be cooled.

## 6. Design

The self-cooling drinking system requires many designs configurations and trials to get the most reliable outcome. Therefore, it is important that during designing, some factors such as weight, size, accessibility, and feasibility are taken into consideration as stated above. The design process consisted of various steps, starting with brainstorming and ending in a 3D CAD-drawing using SolidWorks.
Couple of designs were made but from the morphological map, the design with a higher score was used and hence more focus was put into that design. In the case of this project the design with the most energy went into is the chemical solution. That also resulted in a more simplistic design and allowed for a more reliable user experience. Since the base concept is chemical and mechanical, no electrical parts could malfunction or be affected by the surrounding liquids. Although tests were done with other options, such as using a Peltier-module as cooling element, the chemical solution still proved to be superior in multiple fronts.
To create the prototype a few design choices would have to be made. Below the different choices and steps are discussed.

### 3D Design

Using 3D-CAD software, different designs can be made and tested on different factors, such as size and, using measuring tools, weight. This allows for easy adjustments to be made before the parts are developed. Looking at the designs it can be categorized in two parts. A capsule, which is a one-time-use item and the cooling device. Using a screwing method, the capsule that is inserted can be used. Shaking the device will allow the chemical to beproperly dissolve.
Figure 2, shows the main container, consisting of the lid, which has a plunger which pushes down once the lid is screwed onto the container. The container itself has a spike. By screwing the capsule, the spike penetrates the capsule, releasing the chemical, allowing it to dissolve in the water. By shaking the capsule, the water can, more easily dissolve the chemical, causing the temperature to drop faster. To be able to shake the container, it had to be watertight. To achieve that, an O-ring was added to the lid.
In figure 3, the capsule is portrayed, it has an exact volume to allow for the right amount of Ammonium chloride to be submitted before closing it.

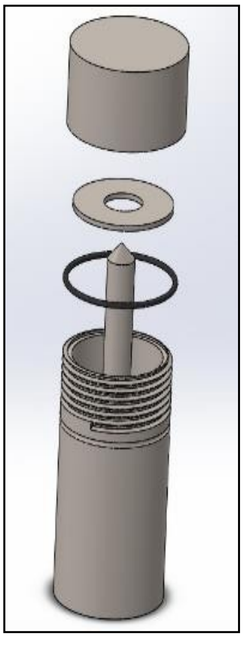


*Figure 2 The exploded view of the contain*

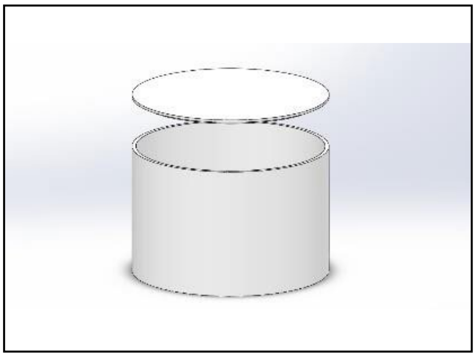


*Figure 3 The capsule with the ammonium chloride*

### Material choice

One important factor of the project is the material choice. This factor is important as it has a few factors which it effects. Not only the weight is an important factor, but also the thermal mass, the thermal conductivity, food safety, and of course the lifetime of the product itself.
Looking at the different factors and materials possible the best option would be aluminum; the downside of aluminum is that it is not regulated for food usage due to possible toxic reactions. The way this can be resolved is to add a small food-safe coating to the aluminum. For the sake of useability and development, the prototype could be made using Stainless steel. It is food-safe and a long product lifetime. On the downside it has a bad thermal conductivity and has a higher weight density, meaning it is heavier than an aluminum option.

## 7. PROTOTYPING

Using prototypes, the development of the product can be measured. If the desired result is reached, the prototype could generate investor-funds or convince other companies to join. It also allows for a better understanding of the device, allowing improvements before the final developed product gets pushed to market.
Using the design discussed in the previous chapter, the prototype can be manufactured and developed. The development of the prototypes was done in cooperation with a company that was willing to help during the COVID-19 pandemic. Due to lack of resources this was a great opportunity to get a valuable product developed. Below, figure 4 the current prototype. This prototype was tested on functionality.

*Figure 4 The prototype op the design*

The capsules, also seen on figure 4, were 3d-printed with a single layer thickness. This allowed it to easily break using the crusher. To seal the lid heat was used to remelt the capsule, stopping any chemical from prematurely reacting with the liquid.

## 8. TESTING

In order to understand if the concept used to cool a camel bag would work, a test has been done. The test had two functions, first it had to show that the prototype was able to crush the capsule and that the chemicals inside the capsule would dissolve in the water. Secondly it had to show that an endothermic reaction took place which was able to cool the water in the camel bag. Two tests were carried out to do this. The test has been carried out with urea instead of ammonium chloride because it was not available in the test location. The first test was executed with the following results. The crushing mechanism of the prototype worked in the right way. However not all the urea was dissolved, and no endothermic reaction was taken place. Therefore, a second test had to be done with a slightly different setup. In the second test the endothermic reaction had been taking place and it was extracting energy from the water in the camel bag. The drop was not huge, due to a small amount of urea that was used. Another test should be carried out with the right amount of ammonium chloride when this is possible. After this test, adjustment could be made on the concept to get the right cooling effect.

## 9. CONCLUSION

The concept chosen for this project has shown various outcome using specific methods. This allowed to really have a great idea about the accuracy to be taken into account when developing a product for important and crucial fields of jobs such as healthcare in this case. The information, research and experiment reflected above give more knowledge and vision to a more elaborated project for the future. Nevertheless, this project was to answer: “How the design and implementation of a Self-Cooling drinking system be useful to contribute to healthcare workers?” The answer to this question, based on the information mentioned, developed, and described, the design and implementation of a self- cooling drinking system allowed to be useful by experimenting an endothermic reaction within a camel bag taking into account the safety and reliability of the product within the healthcare field. Of course, more knowledge could be put in this innovation to alter and improve the system as it is today, but the result did show and answered the question.

The self-cooling drinking system does maintain a percentage of accuracy to an extent but could be improved and optimized. Therefore, couple of recommendation and suggestions were discussed in order to help this product show competence and trust if the potential and opportunity to go on the market arise. The first recommendation would be the optimization of the cooling drinking within its mechanical aspects. Other recommendations would be to put focus on sensitive research and accurate experiment to decrease factors such as weight, cooling time, increase ease of use and finding ideas of activating the cooling system other than shaking the product. Furthermore, it is advised to have more testing of the endothermic reaction; ammonium chloride and also improve the concept design of a suitable camel bag for the final hardware product.

# Literature


[1] “thebmjopinion,” 4 may 2020. [Online]. Available: https://blogs.bmj.com/bmj/2020/05/04/covid-fatigue-is-taking-an-enormous-toll-on-healthcare-workers/. [Accessed 4 may 2020].

[2] D. Oliver, “thebmj,” 8 january 2020. [Online]. Available: https://www.bmj.com/content/368/bmj.l7088. [Accessed 8 january 2020].

[3] A. kahn, “healthline,” 19 september 2019. [Online]. Available: https://www.healthline.com/health/dehydration. [Accessed 19 september 2019].

[4] W. Zeiler, Basisboek, Noordhoff, 2014.

[5] J. Huizen, “medicalnewstoday,” 5 December 2017. [Online]. Available: https://www.medicalnewstoday.com/articles/320226. [Accessed 5 december 2017].

# Innovation of the patient lifting crane hinge

Gijs de Veer, Niels Tosseram, Kar'rar Al Har, Aleksandar Tzvetkov, Wietse van Keulen
Anne Castejon, Guillaume Trossat, Nicolas Gervais, Lucas Lemaire

Fontys University, Engineering, Eindhoven

Ecam University, Engineering, Strasbourgh

**Abstract:** In today's society there are more and more old people who have difficulty moving around. In addition, part of society is partially or completely paralyzed. These people are moved with a patient lifting crane from place A to B. With the current lifting crane this is an uncomfortable operation for the patient because forces are exerted on the shoulders by the sling. The main goal of the project is to create a product that makes the movement of the patient more comfortable. Based on design methods, the project group has succeeded in designing a product where the force on the shoulder is reduced. To this end, various studies have been carried out for both the patient, customers and the market. When designing this product, the necessary calculations have been made such as strength, fatigue and vibrations. In addition, attention has also been paid to the financial part of the product. This includes the costs of materials and production, but also the market and suppliers that are required to sell a product.

**Keywords: Paralyzed, comfort, patient, healthcare, innovation**

## 1. Introduction

In a hospital and for example in nursing homes, people that are paralyzed for 50% or even up to 100% are moved from point A to B multiple times per day by a nurse. The main movement that we focus on is from a wheelchair to the bed, and vice versa. In most cases a patient lifting crane is used to move the person. This movement is verry effective, but it creates a lot of forces on the shoulders from the patient, doing this day in and day out can damage the shoulder joints. Besides the possible damage the movement is not comfortable because of the forces exerted on the body. The patient lifting crane and the forces exerted on the shoulders are shown in Figure 1.


Figure 13 patient lifting crane and example of pressure on the shoulders (Prolift A222).

The problem that needs to be solved is that the paralyzed person is moved from point A to B in a comfortable and in a good way so no damage to the body will occur. This problem came to our attention while performing a survey that we made to investigate the current movement of a paralyzed patient.
This paper will focus on the comfort improvement for the person that is sitting in the lifting crane. Other aspects such as price are of less importance for the project. One thing that cannot be compromised is safety. Because this this product is used in healthcare facilities the product must meet various safety requirements set by the government.

## 2. Concept development

This chapter is about concept creation and the concept selection process. In the concept creation process the functions, requirements and eventually the different concepts are designed. When this is done the concept, selection of the final concept takes place. All of this is done using the methodical design handbook (Zeiler, 2014), which uses four steps to create a good final product.

### 2.1 Concept creation

When the preliminary research is completed the requirements are created. These are created by looking into the problem area, and the problems that need to be solved by this invention. The innovation that is created is will be about relieving the force on the patient's shoulder. This can be achieved by creating more space for the patient's shoulder. With this information the requirements are created.

*User requirements:*

- Reducing the flexibility/tighten pressure within key sections around shoulder joints
- Keeping the standard aspects related within the lifting system constant.

*System requirements:*

- Compatible with standard lifting crane such as the Prolift A222
- Workload at least 2000 [N]
- Lifetime of 10 years or 54.600 repetitions
- Safety
- Maintenance (system reliability)
- Ease of use should not suffer compared to current devices.
- Adjustable to patient's size
- Duration of movement

With these requirements the functions for the concepts can be created. The requirements are shown in Figure 2. With the functions a morphological map is created which later help in choosing the final concept. The morphological map can be found in the final report. To generate concepts and to solve problems, tools like TRIZZ (Zeiler, 2014) are used.

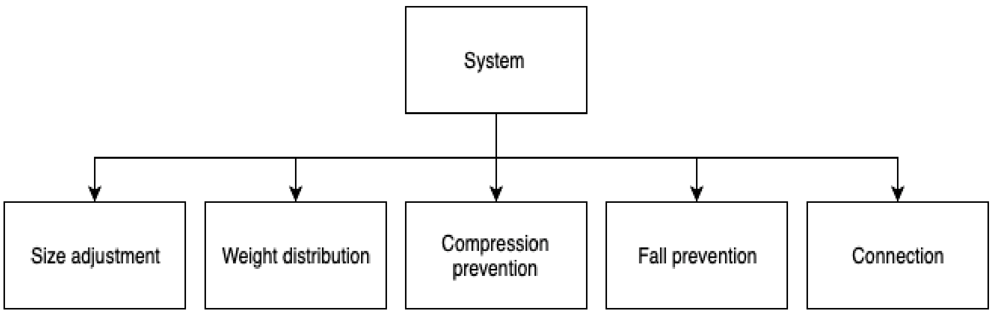



Figure 14 Functions

### 2.2 Concept selection

When the different concepts are created in the morphological map the concepts need to be evaluated. This is done by looking at the set requirements. Every requirement is compared to all the other requirements, this is done to create weight factors for each requirement. These weight factors can be used to grade the concepts. These weight factors create a bigger difference in score for every concept. Eventually four different concepts were created with the morphological map and these are also graded by looking at every requirement. With this method one specific concept will be the best, and this is generally the concept that is used for the rest of the project. In this case the best concept will be used. However, there will be some small modifications to make it better for this project. For example, the best concept made use of a gas spring, because of limited budget the group had to go with a normal spring to make the proof of concept. Making combinations of concepts is not unusual for this method of designing a product. This is done create the best possible product for several requirements. The final concept that is chosen is shown in Figure 3.

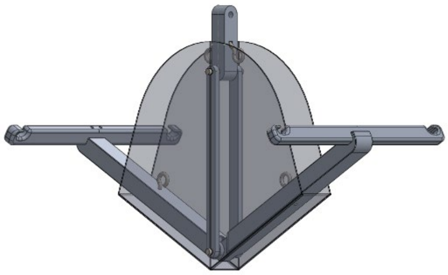


Figure 15 Final concept

## 3. Concept elaboration

### 3.1 Drawing/design

The lifting crane is drawn using SolidWorks, it helps to have an overview of the lifting crane and the different parts that compose it.

### 3.2 Components

The lifting crane is divided in 3 sub-parts: the prehension structure, the spring, and the covering.

The prehension structure is made of 1 vertical axis and 2 arms arranged on either side of the vertical axis, each with a length of 405 mm.

Each arm is surmounted with a horizontal bar of 300 mm long, thus forming 2 T-shaped arms. The 2 horizontal bars are equipped with a standard hook at their 2 extremities, to ensure the compatibility with every transfer sheet. Furthermore, a standard hook is placed on the top of the vertical axis to attach the lifting crane to the arrow of a lifting machine.

The 2 arms provide a 4-point hanging system, it distributes the weight better than a 2-point hanging system, provides more balance during the transfer and puts less strain on the user.

### 3.3 Mechanism

To provide a more comfortable and still safe experience to the user, the arms are attached to the vertical axis at its base with a pivot connection. The pivot connection allows to tilt the arms. As they are not connected, they are independent of each other and can each have their own degree of inclination. The inclination of the arms changes the distance between each couple of hooks and thus change the direction of force application. To prevent the arms from tilting too much, a stop is placed at the bottom of one of the arms.

To be the more comfortable as possible, the forces that the sheet straps apply to arms must be oriented vertically so that the sheet does not compress the patient. The variable inclination of the arms allows to provide that right spacing between the hooks to give more space for each patient, according to his weight, during a transfer.

To set the inclination of the arms, the lifting crane is equipped with 2 identical springs. Each one of them is attached to an arm and to the vertical axis. The heavier is the patient, the more the spring will extend and spread the arms.

### 3.4 Security

The security aspect is very important both for the patient and the medical staff.

An aluminium cover is placed around the lifting crane. It has 2 main purposes:

- Protects the users from spring splinters in case of breakage.
- Reduces the risk of pinching at the pivot joint.

### 3.5 Calculations

In this chapter, different calculations for both the spring and the sling are shown.

### 3.6 Sling Calculation

First to explain the calculations, the use of abbreviation is recommended, it can be shown in the table 1. Then, the force on the shoulder is calculated with the FBD of the sling. To calculate the force on one shoulder, basic trigonometry is used. Because of the size of the patient and the shape of the sling, forces are created that push on the shoulder joints. This force can be determined by using the force created by the patient.

| Abbreviation | Explanation |
|---|---|
| Wb | Width butt |
| Wh | Width hinge |
| Ws | Width shoulder |
| Cb | Circumference butt |
| Lb | Length body |
| Ltot | Length total |

*Table 1 Abbreviation*

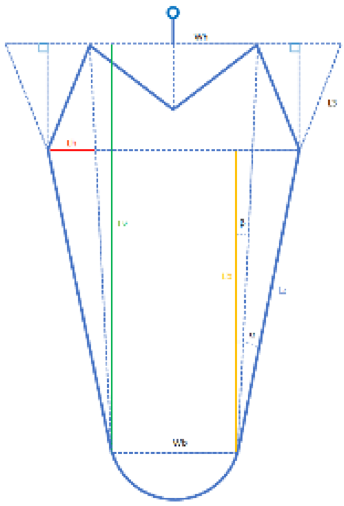
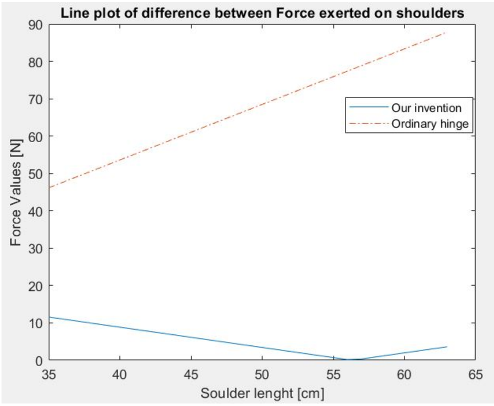


Figure 16 FBD of the sling

With those diagrams, and after working on the equations, the team ended up with one equation that will determine the force applied on each shoulder. The total weight Fg is divided by 2 and by the length of the sheet and multiplied by the length of a shoulder (Lh). The output of these calculations is based on 29 different sizes of shoulder widths, hip widths, hip circumference, patient body lights and patient weight. By having 29 different inputs, it can show that the pressure on the shoulder is reduced by as much as 10 times compared to the static lifting hinge that is currently on the market, see Figure 4.

Figure 17 Our product compared to current product




In the next part, the calculations for the hinge are done. The most important force that needs to be determined is the force acting on the spring. The only real force acting on the hinge is the weight of the patient, known as Fg.

So, for the full force applied on the spring, this result needs to be multiplied by two. This equation will help the team decide in what type of material the spring will be made.

After working on the equations, the result of the force of one side of the spring is:

$$Fs = \frac{\frac{Fg}{2} * \sin\left(\frac{\gamma}{2}\right) * \left(L1 + L2\right)}{cos\left(\frac{\gamma}{2}\right) * L1}$$

### 3.7 Spring's Extension

Next, the extension spring need to be determined. An extension spring is a coil that is twisted into a spiral and securely wrapped to meet various tension requirements. The application in which the spring is associated with the desired application, is key in determining the extension spring type and end type of the most suitable spring design. The intention of an extension spring design is to provide extended force when a force is applied to the spring separating it from its primary length.

First, to calculate the spring's inner diameter from outer diameter. Multiply the wire diameter by two and then subtract the result from the outer diameter. **ID = OD – 2WD = 44,45mm.**

Then, the team can calculate the spring's mean diameter.

This specific dimension is calculated by taking one wire diameter and subtracting it from your compression spring's outer diameter or adding one wire diameter to the inner diameter. **ID + WD = MD = 53,975 mm.**

Now that the team has both Mean Diameter and Wire Diameter, the index can be calculated. This spring calculation is needed to make sure that the spring you require is manufacturable. The mean diameter must be divided by the wire diameter. **I = MD/WD = D/d = 17/3.**

The two most common types of extension spring ends are machine and crossover centre hooks. After comparing those two extensions, the team decided to use crossover centre hooks. Here is how to calculate an extension spring's length inside hooks from body length. Multiply Inner Diameter of the extension spring by two and add it to the body length. **2 ID + BL = LIH; BL = 635 mm.**

For the next part of calculation, the team decided to make the spring in aluminium. Calculating the extension spring's rate is a tough task since the equation is made with various variable. Here is what the rate k represents for the spring. **k = Gd^4 /[8D^3 na] with G = E/2(1 + V).**

This representation of the rate will be useful for the next and last part of the spring calculation, and its link to the extension spring's initial tension. Initial tension is the force/tension between the extension spring coils before being extended., and can be calculated using the formula shows below:

**Load = Stress * Wire Diameter ^ 3 ÷ 2.55 * Mean Diameter = Sd^3/2,55D.**

## 4. Business plan & costs

In this section the business side of the project is discussed. Thins such as the mission and vision are explained, what kind of market is applicable for the product and how to tackle everything.

### 4.1 Mission & Vision

A mission is something an organization stands for and wants to work towards. This is something an organization stands for and actively works towards. The vision is something an organization wants to see in the world. This does not need to be something an organization is responsible for or can achieve. To communicate what the organization stands for a mission and vision is stated below:

- Mission: Allow paralyzed individuals to do daily activities without discomfort.
- Vision: A world in which everybody can move around in a comfortable and free, way.

### 4.2 Customer & market research

This product will be serving in a niche market, because it specializes in the movement of a paralyzed person and the comfort of this person during this movement. The market of lifting cranes and their accessories is part of the bigger market, the market that supplies medical gear. The main market we focus on is the healthcare environment. This can differ from hospitals to nursing homes and even insurance companies. The focus of our product is to serve that persons that need this invention. These people are mostly elderly and disabled persons.

The healthcare market and especially the medical gear market is relatively small, and customers tend to stay with their current supplier. Therefore, a business to business (B2B) model is best suited for this product. the product is sold to an already existing supplier of hospitals and nursing homes so the market can be entered as well.

Besides the suppliers and customers, we investigated the end user of the product as well, the disabled and elderly people. The group with an age of 80 or older will be doubled from 0,8 million in 2019 to 1,6 million in 2030, see Figure 6. This number will grow even higher to its maximum peak in 2053 of 2,1 million. In percentages the age group of 65+ will grow from 19% to nearly 26% of the total population of the Netherlands (CBS, 2019). This growth of elderly people is beneficial for the product because more people end up in nursing homes.

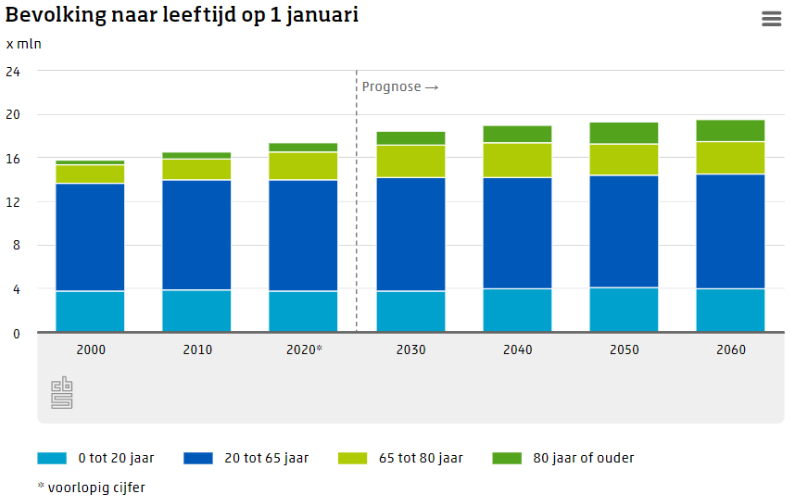



Figure 18 Population growth the Netherlands

As shown in Figure 7 the expenditure on health care increases over the years. Also, the expenditure for disabled people and nursing homes is increased which results in more money for healthcare gear such as our product.

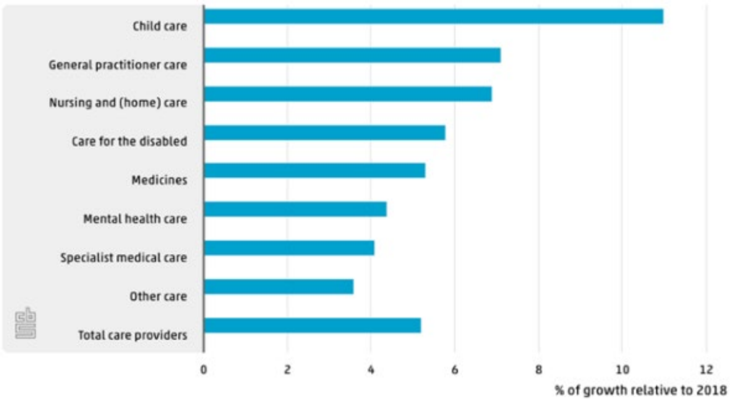



Figure 19 Increase in expenditure on care (CBS, 2020).

### 4.3 Business strategy

The strategy chosen for the product is based on the value disciplines of Treacy and Wiersema (M. Treacy, 1993). Our product will excel in Product Leadership. This strategy has been chosen because the product is an incremental innovation where the customer's wishes are high. This is an innovative product that improves the lift crane, making the existing product (the lift crane) even better.
The Customer Intimacy value discipline responds to a minimum threshold level, because our company builds individual relationships with their customers. We as the future company are aware that building customer relationships in a business-to-business market is of great importance. Although we do respond to customer intimacy, the focus remains on delivering 'the best product'.

### 4.4 Business model canvas

To create a proper business plan, we started with a business model canvas (Tankink, 2020). This is a tool to quickly see where opportunities lie. What should stop working on and what should we continue or start working on. This way you can continue grow and innovate. It's a simple model that is always adjusting. Every building block is dependent on the others.

### 4.5 Marketing strategy

The marketing mix formulates a marketing strategy based on the 4 P's by (Visser, 2018). These include: Product, place, price and promotion. A fifth P can be seen in personal. The 4P model is a tool to create a marketing strategy.
The earlier product includes the following parts:

1. **Connection beams:** These are used to connect the sling to the hinge. The four connection points create a shape in the sling which reduces pressure.
2. **Centre beams:** These beams create the core of the hinge.
3. **Spring:** The spring is the innovative part of the product. The spring allows the hinge to adjust its shape according to the weight and size of the patient.
4. **Connection rods:** The vertical rods are separated from the top beam to allow the spring of the system in-between to function. These rods are identical.
5. **Top beam:** This beam connects the hinge to the lifting crane. The top hole is perpendicular to the bottom. This way the hinge is connectable to the crane.

The team is internationally oriented. The first focus will be The Netherlands. After that France will be targeted. Once these two markets have been built, the rest of the European market is targeted. The target group are health insurance companies and hospitals in The Netherlands. Households often buy healthcare equipment through their insurance. This means that the product should be approved by these insurance companies to have a chance of success. Hospitals and nursing homes are responsible for their own Equipment. The product saves cost for its consumers since they won't have to buy a full new system like a transformable wheelchair or a lifting crane. The product can be attached to an already existing lifting crane. The product itself is focussed on quality therefore the price for the individual piece will be

### 4.6 Financials

The financials for the product can be separated in 3 classes: Product materials, equipment, development and production costs. The development costs are neglectable in this specific case. The product is developed by students which takes away the personnel costs.
The material costs add up in-between €50, - and €100, -. The production costs are yet unknown. Exact calculations must give an indication. The product needs to be assembled and the beams and rods need operative work.

## 5. Conclusion

The final concept meets the established requirements and improves the transfer of a patient from a bed to a chair via a lifting machine. Safety is maintained and comfort is improved with the spring system during the transfer. The lifting crane is also compatible with existing machines, which considerably reduces the cost and investment for interested institutions, making it easier to purchase.

### Thanksgiving

We thank Fontys university of applied sciences and ECAM Strasbourg Europe University for their contribution to this paper and project. Their guidance and facilities allowed the team to work on this project. We would like to thank Mr. M. Samsam individually for his guidance and contribution to this project in his role as coach.

## 6. Literature:

CBS. 2019. CBS. *CBS.* [Online] 17 12 2019. [Citaat van: 27 12 2020.] https://www.cbs.nl/nl-nl/nieuws/2019/51/prognose-19-miljoen-inwoners-in-2039.

—. 2020. Z orguitgaven stegen in 2019 met 5,2 procent. *CBS.* [Online] 11 06 2020. [Citaat van: 27 12 2020.] https://www.cbs.nl/nl-nl/nieuws/2020/24/zorguitgaven-stegen-in-2019-met-5-2-procent.

Treacy 1993 M. Treacy, F. Wiersema. 1993. The customer connection. *Customer Intimacy and Other Value Disciplines.* [Online] 1993. [Citaat van: 27 12 2020.] http://thecustomerconnection.nl/docs/member94427/Customer%20Intimacy%20and%20other%20value%20disciplines%20(Treacy%20&%20Wiersma).pdf.

Tankink, Andree. 2020. Business Model Canvas. *KVK.* [Online] 24 12 2020. [Citaat van: 27 12 2020.] https://www.kvk.nl/advies-en-informatie/innovatie/productontwikkeling/business-model-canvas/.

Visser 2018 Visser, Bronis Verhage & Marjolein. 2018. Marketingmix. *Grondslagen van Marketing.* Utrecht : Noordhoff uitgevers, 2018.

Zeiler, Wim. 2014. Het methodisch ontwerpproces. *Basisboek ontwerpen.* Groningen-Houten : Noordhoff Uitgevers, 2014.

—. 2014. TRIZ p.331-335. *Basisboek ontwerpen.* Groningen-Houten : Noordhoff uitgevers, 2014.

# Solar Water Treatment

Steven Chen, Thijs Luijten, Siem Dirkx, Dorus Zwienenberg, Joep Tacke, Leonardo Bonnefous, Guillaume Astrie, Quentin Ramen, Nicolas Scheffelmeier

Fontys
Fontys Universities, Engineering, Fontys
ECAM Strasbourg, Engineering, Strasbourg

**Abstract:**

Safe drinking water is one of the most important resources for humans to stay healthy, but safe drinking water is not for everyone available. With the solar water treatment concept this is will be possible by filtering dirty unsafe water with the energy of the sun. Therefor the concept focusses on the people around Lake Victoria. Because the water from lake Victoria is not safe to drink, but lots of people depend on the water of this lake. The technology uses a filters that clean the water for a reliable outcome every time. This concept is a great invention for charity's to provide them with clean drinking water.

**Keywords:**
Mechanical engineering, Mechanical design, Innovation, Solar water treatment, Start-up

## 1. Introduction

Water scarcity is still one of the world's biggest leading problem. Water scarcity is affecting almost 1.1 billion people globally. This means that one in every six people lacks access to safe drinking water. The most immediately apparent impact of water scarcity in Africa is on the continent's health. With a complete lack of water, humans can only live up to 3 to 5 days. This often force them to use unsafe water sources which, according to the WHO, contributes to the spread of waterborne diseases. However, many of these waterborne diseases are preventable. Globally, 2.2 million people die each year from diarrhea-related disease. Creative and innovative are therefore desired to create a solution for the water scarcity.

Our project group consist of students from the Fontys University in Eindhoven and the Strasbourg University in Strasbourg. We started the project to design a water purifier (water filtration-system) on solar energy. This water purifier needs to 'clean' (filter) the unsafe water from the resources. With this project we want to fight against water scarcity and solve one of the world's leading problem.

This paper will summarize our innovation to fight against the water scarcity. The paper will give the reader an idea of the system. If the reader wants more specific information he can contact a member of IE10 for the full report.

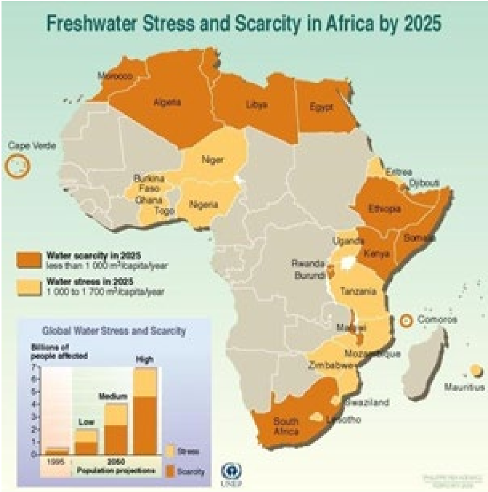



*Figure 1: Freshwater Stress and Scarcity in Africa by 2025*

## 2. Requirements

Develop an innovative optimally sized and easily controllable modular solar water treatment system for areas with abundant solar energy.

### Solar water treatment:

Sustainably use solar energy to treat water for domestic useNo additional energy source needs to be used, other than solar energy.
Human interaction can be needed.

### Product:

- The product must be easy to use for all humans above the age of 10.
- Using the system requires simple handling. (Pushing button, simple movements, etc.)
- The water treatment method can independently operate.
- Easy human interaction to promote the water treatment is acceptable.
- The product can be fixed to a singular place:
- Plug & Play.
- The product provides clean water a day for an average African household.
- The size of the product cannot be bigger than 1,0 x 1,0 [m] and not higher than 1,0 [m]
- The product can be used for at least 10 years.
- Guidelines for Drinking Water Quality (GDWQ) according to the World Health Organization (WHO): E. coli or thermotolerant coliform bacteria in treated water must not be detectable in any 100 [ml] sample. Limits given by the WHO on naturally occurring constituents that may have direct adverse health impact cannot be exceeded.

While designing the system, those requirements are taken in account. Each of the requirement has an import meaning for the use of it. The plug & play requirement is important for the use of it, like the automated part. The users of it do not have to do specific actions to get filtered water. The water treatment will work on solar energy, this is because the area where the product will be used is plenty of sun (12 hours a day).

The filtered water will be used for household and drinking. To specify the water as drinkable water it also needs to meet some requirements. Those requirements are given by WHO (world health organization). To see the specifications of the drinking water, see our full report.

If the product meets all those requirements the goal of the project will be achieved.

## 3. Design choices

By brainstorming for the different aspects within the water treatment system, several different aspects are written down. For each aspect, several solutions and ideas are created. The gathered information is written in a morphological chart to create an overview of the possibilities within the system.

| Retrieving the water | Water treatment methods | Transporting water in system | Energy source | Water storage |
|---|---|---|---|---|
| Carrying T4 | SODIS | Manually | Solar panel | Watertank |
| Water pump | Water pasteurization | Water pump | Wind | Reservoir |
| Hand pump | Sand filtration | Hand pump | Battery | Water tower |
| Mill_mechanism | Distillation | Mill mechanism | Hydropower | Water cans |
| Mill_mechanism (automatic) | Filters | Mill mechanism (automatic) | Tidal power | |
| | Reverse_osmosis | | | |
| | Chlorination | | | |

Table 1: Optimal time working range per method

After this design we realized that a SODIS may not be sufficient to filter as much water as our requirements. This meant we had to take on a different way of cleaning the water. We started by analyzing water filtration on a more abstract scale. After a while the group made the decision to choose a nanofiltration filter in combination with some kind of pressurizer.

### 3.1 Calculations

After having a better idea of how the final product should look, we decided to make the most important calculations. The pumps needed pressure for the pump are calculated and the power delivery of the solar panels. The solar panel needs to deliver enough energy for the pumps. Those calculations are worked out in the full report.

### 3.2 Concepts

The set requirements for the solar water treatment for the hardware are as following;

**Energy.** The energy needed or used by the product needs to be from solar energy only. No additional energy sources, other than solar energy and human interaction, can be used. Transferring solar energy into usable electric energy is possible.

**Mechanism.** The product must be easy usable for all humans above the age of 16. The product can independently operate. However, an easy human action to promote the water treatment is acceptable. The product can provide clean water for a household of 6 persons/ the product can provide 70 [L] of clean water a day.

**Materials.** The product needs to be made out of > 80% recyclable or reusable materials.

**Structure.** The product will not be fixed to a singular place but can be carried around (while not in use/no water). Therefore, wheels are optional, but not a necessity. The size of the product cannot exceed 0,5 [$m^3$].

**Water quality.** The guidelines for drinking water quality are set by the World Health Organization (WHO). E. coli or thermotolerant coliform bacteria in treated water must not be detectable in any 100-ml sample. Limits given by the WHO on naturally occurring constituents that may have direct adverse health impact cannot be exceeded.

See figure 2 for the concept made in NX 10 with all the hardware to make the concept work.

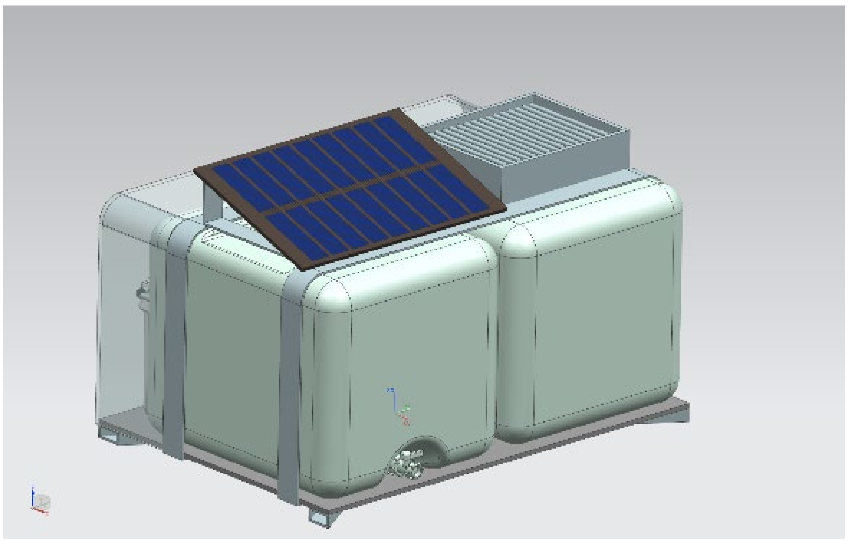


*Figure 2: Final concept with all requirements*

### 3.4 Filters

A water purifier can filter water in many ways, our filter will use a heavy metal filter for the heavy metals. Further on our system will use SODIS (solar water disinfection). The water will first be pumped through the heavy metal filters to filter the big particles. The filtered water will go through the SODIS system that will clean bacteria's, viruses, protozoa and worms. The SODIS system works on solar power, it's a combination of the heat and ultraviolet light collection that will purifier the water, zee table 2.

| Water treatment method | Differences | Optimal working range |
|---|---|---|
| SODIS | Sunny day | 6-8 hours |
| | Cloudy day | 2-4 days |
| Pasteurization | At 60 – 90 °C | 20-50 minutes |
| Sand Filtration | Rapid sand filters | 15-120 minutes |
| | Slow sand filters | 2-4 days |
| Distillation | (20 drops/min) | 3-4 days |
| Filters | Dependable on filter | 2-5 minutes |
| Reverse-Osmosis (filter) | | 2-5 minutes |
| Reverse-Osmosis | | 1-2 day |
| Chlorination | | 30-60 minutes |

Table 2: Diffent ways of filtering water, with there processing time.

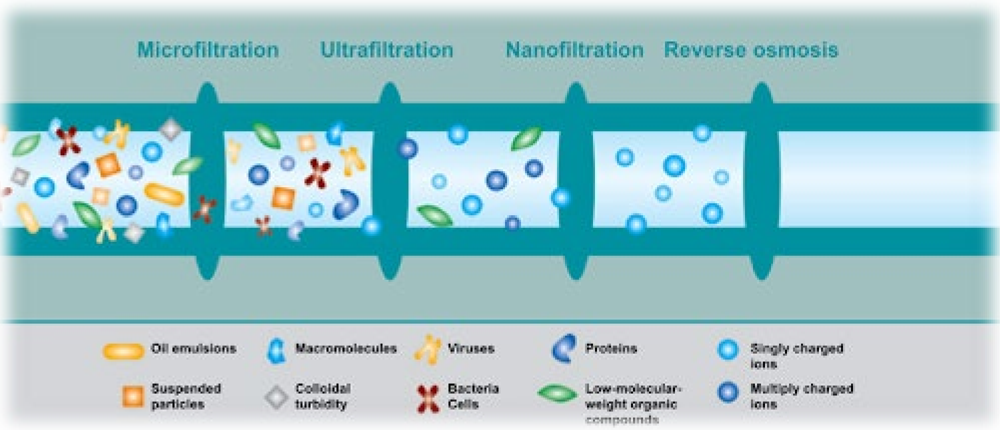



*Figure 3: Different ways of filtration*

With an expert from NX-filtrations we decide to go for a Nano-filter, these filters are acceptable in purchase. These filters also filter the heaviest metals and bacteria out of the water. To use a nano-filter, the systems need pressure. Because it's a pressure driven membrane. It has to take in account that the pump needs to be powerful enough.
Nano-filters are often used for low total dissolved solids water such as surface water and groundwater. Our water source is a lake, so it suits in our case.

## 4. Future possibilities

The best combinations create several final concepts. Each concept is given a score based essential competences. Giving weight factors to the competences will give a final score per concept. The four concepts selected: Filtration, SoDis, SoDis + Filtration and Distillation. By subjecting the concepts to the DFX method, a filtering on requirements could be made

### 4.1 Our concept

Using an ultra-filter, the water will be treated to get clear drinkable water which meets the requirements on water quality. However, an ultra-filter requires a pump which gives the necessary pressure to get water through the filter. For the pump an electrical pump can be used. Further research will determine whether a handpump can also be used.

### 4.2 SODIS

SoDIs is a solar water treatment which clears water only using sun light. SoDis is a type of portable water purification that uses solar energy to make biologically-contaminated water safe to drink. To be able to use the SoDis method, the water needs to be clear. As this could be a problem in de selected areas, a fast-filter is needed to get the clear water needed for SoDis.

### 4.3 SODIS + FILTER

To get a better water quality, a combination between SoDis and the use of filters can be made. This will contribute to a better water quality and a more secure result.

### 4.4 DISTILLATION

Distillation is an effective way to clear water. By vaporizing, the water will be clear of contamination. This method only needs a heated element which can come from solar energy in the form of solar panels.

## 5. Epilogue

The solar water treatment, is a good invention for people around lake Victoria. Because this concept will make the water of this lake safe to drink and it is reliable. The concept that was chosen by the diagram in is filter, this is the best concept of the four concept that were described in the rapport. But there is one problem there still a few points unclear, first of all the materials not of components are chosen yet. This means that there were made a few assumptions in this rapport. In the cost analysis there were a few assumptions on how much the components would cost. In these assumptions there was a 10% extra calculated just in case the assumptions weren't accurate enough. But like the cost are right know it looks like it's possible to make a proof of concept with 200 euro's.
To conclude, most of the requirements are met with the concept of filter. But still there are uncertainties with the components and there for with the cost of the components. So when this concept will be realised keep looking back at if the conclusion from is that it isn't a good idea than go back and start again until a perfect concept is designed.

## Literature

Africa, E. (n.d.). Retrieved from ESI Africa: https://www.esi-africa.com/industry-sectors /water/kenya-water-and-sanitation-access-around-lake-victoria-to-be-upgraded/

Metoblue. (n.d.). *Kampala Uganda*. Retrieved from Metoblue: https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/kampala_uganda_232422

Reed, B. (n.d.). *How much water is needed in emergencies*. Retrieved from WHO: https://www.who.int/water_sanitation_health/publications/2011/WHO_TN_09_How_much_water_is_needed.pdf?ua=1

WHO. (n.d.). *WHO*. Retrieved from WHO: https://www.who.int/news-room/detail/12-07-2017-2-1-billion-people-lack-safe-drinking-water-at-home-more-than-twice-as-many-lack-safe-sanitation

WHO. (n.d.). *WHO*. Retrieved from WHO: WHO. (2018). WHO. Retrieved from Afro.WHO: https://www.afro.who.int/health-topics/water

# BullsAi Gym Tracker

Teun Jacobs, Rob Kerkhofs, Niels Maas, Mihail Marinov, Rafaël Weber

Fontys University of Applied Science, Engineering, Eindhoven

Rafaël.weber@student.fontys.nl

**Abstract:**
This paper aims at providing the reader the insights of the function behind the Bulls'Ai. The details of the electrical part of the system has been explained of how the hardware and software came together into final product so data can be collected. The final results of the design and why chooses had to be made is written down in the mechanical part. By using 3D modelling, the outside casing for the electrical parts is completed. Because of the businesses potential a lot of attention has been put into developing ideas for the perfect start up. Thinking like an entrepreneur with models like the Lean Canvas and Value Proposition Canvas was priority to get an idea of how the average gym trainee sees an automated gym tracker implemented in their training program. At the same time these model validated the business model and its minimum viable product. To answer the main question, a few sub-question were derived. Those are split into three departments: Electrical, Mechanical and Business. The sub-questions will be stated on top of the three main chapters.

**Keywords:**
Innovation, automated fitness tracker, PCB, Design, Lean Model

## 1. Electrical

For the electrical part of the system a few questions had to be answered:

- Is the system able to handle the x,y,z data with a frequency of 240Hz?
- Can the electronics be small enough to fit on a wrist?
- Is the system able to make a connection with a phone via Bluetooth?
- Can the accelerometer sample the three axes on minimal frequency of 240Hz?
- Which battery will be the optimal choice for the wearable?
- How to manage the battery and provide the necessary power for the other modules?

All these questions have been answered and the solution will be explained below.

### 1.1 Is the system able to make a connection with a phone via Bluetooth?

After choosing the components, the first thing to test was making connection with a phone via BLE. Using an example code for the esp32, the team was able to make a connection with an iPhone with the NRF connect app. This app is used for reading the BLE signals because the final phone app will be made by an external party. For the project only unidirectional communication was necessary, so the first test was sending a constant to the phone and reading it. After this, the bidirectional data transfer was already tested to possibly extend the capabilities in the future.
This test also showed the conversion type of the BLE to the phone. When sending a character to BLE the character is first converted with utf-8 to a hexadecimal number; sending an A will result in 0x41.
Another company is working on an app to process this data, therefore a few agreements had to be made for sending the data. The data will be sent as:

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | x4 | x3 | . | x2 | x1 | x0 | Y | y4 | y3 | . | y2 | y1 | y0 | Z | z4 | z3 | . | z2 | z1 | z0 |

*Figure 1: BLE data frame*

First the axis will be sent as a capital letter, than the 5 digit data with a dot. This repeated for every axis. It will result in 21 bytes.

## 1.2 Is the system able to handle the x,y,z data with a frequency of 240?

Handling the data will be done in the controller. The controller speed is often in the MHz range so it can be neglected. Next to that, the BLE chip inside the controller could be an issue. First, the relevant information about BLE is given, after it the results.

### BLE

BLE stand for Bluetooth low energy. It is different from normal Bluetooth and is often used for devices which run on a small battery like wearables or headphones. BLE makes use of the same frequency band as normal Bluetooth and it can coexist in one device. BLE is built with the BLE stack which looks as following: [1]

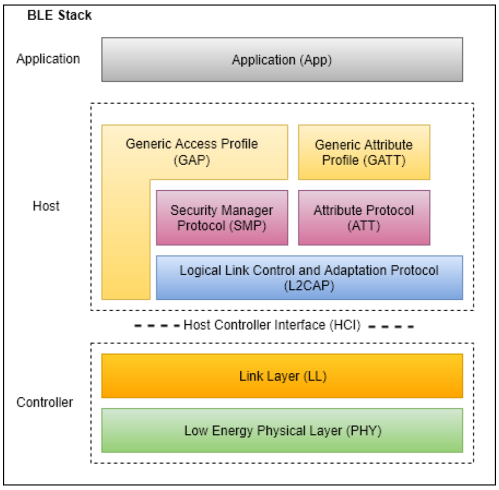



*Figure 2: BLE STACK*

This BLE stack contains all protocols needed to form a BLE connection. The relevant part of it is the number of "building blocks" needed to make a BLE connection, it consists of many layers that insure a two way, handshaked data transfer.
The figure above shows the overall BLE stack. It includes all layers needed to set up the BLE connection between two or more devices. Sending a message over BLE with BLE V4.0 and BLE v4.1 is showed in Fig. This shows the overall overhead data send per message. This means: with a message of 23 bytes there are an extra of 14 bytes of data needed to send the message.

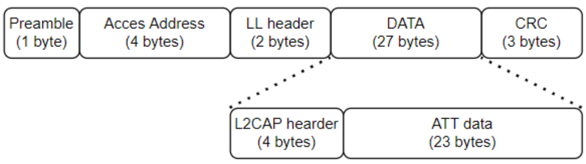



*Figure 4: BLE V4.0 V4.1 data packet*

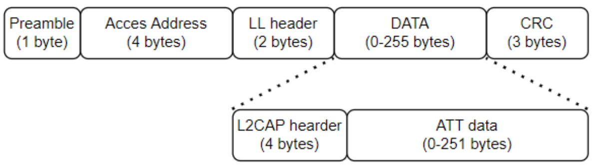



*Figure 5: BLE V4.2 data packet*

In the newer BLE V4.2 a new feature was added to increase the data packet up to 255 bytes.

The BLE speed is the hardest part of this question, the speed of BLE depends on the distance between sender and receiver. If the distance between them exceeds 15m the signal will decrease a lot. [2]
The speed also depends on size of data that will be send. In this project the data will be x, y and z axis. These will all have a precision of 0.001 because the more precise the data, the better the AI can learn. An acceleration that

exceeds 99.999 is not realistic when working out in the gym, therefore the number of bytes send per axis will be 6 bytes.
Looking at figure 4 the overhead of bytes is 14 bytes and looking at Figure  the total data send will be 21 + 14 = 35 bytes of data.
The theoretical transfer rate of the controller chosen is 90 KB/s. Looking at equation (1) this results in a maximum speed of 2.57KHz.

$$sending\ frequency = \frac{BLE\ frequency\ (\frac{B}{s})}{number\ of\ bytes\ to\ send(B)} = \frac{90000}{35} = 25714Hz \qquad (1)$$

Looking at the results of the calculations it can be concluded that the controller is able to handle the data with a frequency of 240Hz. [3]
Except, there is one problem: not all phones have the same BLE frequency. An iPhone 6 for example only has 2667 B/s. This leads to a whole new problem. For this BLE to meet the requirements we need at least a frequency of 240Hz. Rewriting the formula gives us:

$$minimal\ BLE\ frequency = sending\ frequency * number\ of\ bytes = 240 * 35 = 8400\ B/s \qquad (2)$$

This BLE frequency can not be guaranteed for every phone so the BLE connection is not always fast enough.

### 1.3 Can the accelerometer sample the three axes on minimal frequency of 240Hz?

The first thing to look at was if the accelerometer and controller would communicate at a high enough speed for the system to work properly. The connection between these two is I2C which stands for Inter Integrated Circuit, which is a synchronous data transfer protocol. This protocol uses two wires: Serial data and Serial clock. The clock will always be chosen by the controller so in this case the esp-wroom32. The Esp. initializes the clock in standard mode which is 400KHz. The frequency of the I2C is way higher than the actual sample data and the required frequency so the I2C connection is no problem.
The accelerometer itself could also be an issue. Looking at the datasheet of the MPU6050 the maximal output data rate is 1KHz. This is way higher than the 240Hz so also not a problem.
Accelerometer:

| | | | | | | |
|---|---|---|---|---|---|---|
| **LOW PASS FILTER RESPONSE** | Programmable Range | 5 | | 260 | Hz | |
| **OUTPUT DATA RATE** | Programmable Range | 4 | | 1,000 | Hz | |
| **INTELLIGENCE FUNCTION INCREMENT** | | | 32 | | mg/LSB | |

*Figure 6: MPU6050 output data rate*

Looking at the picture above the accelerometer is fast enough, however the data is not directly sent to the controller. It is sent to the fifo (first in first out) of the chip. The fifo output data rate depends on the sample rate which is set when setting up the chip in the controller.
The gyroscope output rate is set on 8000Hz and the sample rate divider on 32 which results in:

$$\text{sample rate} = \frac{gyroscope\ output\ rate}{1+sample\ rate\ divider} = \frac{8000}{33} \approx 242Hz \qquad (3)$$

To conclude, the accelerometer and its connection with the controller are fast enough to meet the requirement of 240Hz.

### 1.4 Can the electronics be small enough to fit on a wrist?

The next challenge was fitting all the electronics on a wrist. The average wrist is between 35 and 40 mm. This means the electronics cannot be larger than 40 mm on one side and the other side should not be twice that for aesthetics. Using the chosen parts, the team was able to make a PCB (printed circuit board) within those constraints. The PCB is shown in figure 7.

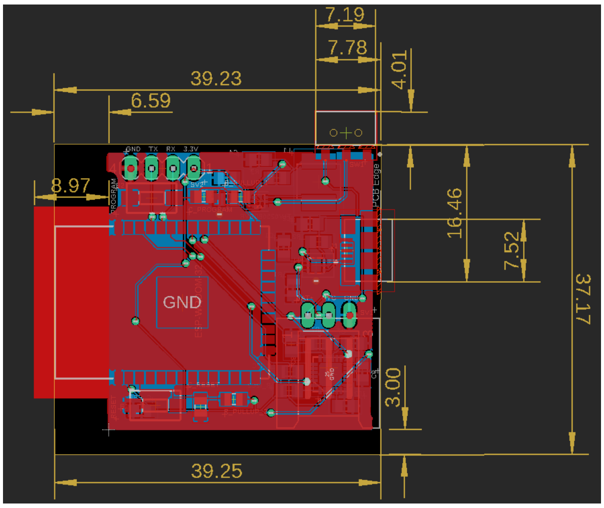



*Figure 7: PCB design*

The PCB shown above has a size of 39.25 by 37.17 mm. A casing still has to be added on it, but it will fit on a wrist.

### 1.5 Which battery will be the optimal choice for the wearable?

Battery choice is important for any wearable as it dictates how long the device can be used without recharging which can draw the line between a successful product and a failure. Being one of the biggest components in the device, the battery has implications on the external design of the device. Therefore, it is important to find the battery with the biggest capacity for its volume, but also manages to fit in the available space without affecting the external design of the device.

The requirements for the battery imposed by the mechanical team are that it should fit in a cuboid with a size of 30x25x6mm. As the device case will be 3D printed, small deviations from those sizes are possible, but this volume is used as a general goal for choosing a battery. Ultimately the casing is designed by the project team and the batteries are done by a third party, so the batteries are impossible to adjust.

The team has decided that the battery must be rechargeable instead of swappable. It was also decided that the battery should last 10 hours of workout time, but as of the time of the design, it is unclear how much power the components will use in a real workout situation. Although the power usage of the accelerometer, buck converter and battery protection circuit can be taken from the datasheets, the ESP32's power usage is impossible to predict. This is since the ESP32 has different submodules that can be turned on and off and affect power usage. This microprocessor also has 2 cores that can be used at different frequencies that would also affect power usage. Therefore, the battery with the most capacity that fits inside the given space will be chosen and the actual battery usage will be determined when the first prototype is ready.

**Lithium-ion/Lithium-polymer (Li-ion/Li-po)** batteries are the preferred choice for small sized products such as mobile devices, wearables or laptops. Their main benefits are that they have big energy density and are light. Moreover Li-ion batteries can have more flexible form factors than Ni-Cd and Ni-Mh batteries, thus could be a better choice to fit the required dimensions. Lithium-ion batteries also have a fast-charging time ranging from an hour to two hours. The main drawback of li-ion batteries is that they are unstable and must be handled with care. This means that they should be protected from physical damage inside the product's casing and also have a proper battery management system to protect them from being damaged by overheating, overcharging, overconsumption or other electrical hazards. A slightly more stable version of lithium batteries are the lithium-polymer batteries, which gain some robustness at the cost of lower energy capacity and higher price.

**Table 2 Battery options**

| Battery model | MULTICOMP LIR2450 | PULUZ 402030 | BAK LP-402025-IS-3 |
|---|---|---|---|
| Capacity | 120 mAh | 200 mAh | 165 mAh |
| Voltage | 3.6 V | 3.7 V | 3.7 V |
| Dimensions | Circular 24.5(d)x5mm | 30x20x4mm | 26x20x3.8mm |
| Price (individual) | 3.03 Euro | ~8 Euro (excl. shipping) | 16.13 Euro |
| Availability (30-Nov-20) | 171 | Only overseas | 5,647 |
| Internal PCB | No | Yes | Yes |
| Technology | Lithium Ion | Lithium Polymer | Lithium Polymer |

Despite the high price the LP-402025 is the best and the only possible choice for this project. It is available in Europe and thus can be shipped easily in time. Moreover, it almost fully fits in the designated battery space, thus the capacity is close to maximum for the given volume. As already mentioned for a real product, a better battery choice can be made as bulk orders enable more overseas import options and working with industrial suppliers, which do not sell individual units.

### 1.6 How to manage the battery and provide the necessary power for the other modules?

A battery management system has the purpose of managing the operation of the battery so that it is operating at safe conditions and prolonging the life cycle of the battery for as long as possible. The battery that will be used is LP-402025 and has a nominal voltage of 3.7V, typical capacity of 165mAh with a recommended charge current of 78mA [4].

The project's goal is to make an MVP and a proof of concept for a wearable fitness tracker. From the mechanical team there is a design goal of fitting all electronics in a 30x25mm area, so PCB footprint is the main limiting factor for the overall circuit. The BMS is not an exception to this. The size constraint means that SMD components will mainly be used.

For this particular BMS there was a component that stood out. It is a highly integrated package that offers all necessary functionality. This component is bq25120A by Texas Instruments. It combines thermal protection, battery charge and discharge management, battery charge level monitoring and a buck converter. Since those systems are all combined in a single IC the PCB footprint will be smaller, compared to using multiple components. Moreover, this chip can be programmed through IC2 protocol, which saves even more space on the PCB, since less external passive components are necessary.

This choice of battery charger, buck converter and battery protection was indeed the best choice for such a product; however, it is very complex to use. Although the circuit was built carefully and checked, there was no way to simulate the circuit behaviour or, unless a prototype was made. Doing one off prototypes, which cannot be built in house at the university is a costly and timely process, so the group decided that it was a better option to make a simpler system. This simplification requires a bigger PCB footprint and cuts off some features of the battery system, however it maximizes the chances that the prototype will work from the first iteration. Otherwise, there was a high chance that the prototype does not work from the first time.

The new basic design involved only a buck converter to step down the voltage from the 3.7-4.2V that the battery outputs depending on its charge level to 3.3V that the MEMS accelerometer and the ESP32 require. The chosen buck converter controller IC was TLV52568DBVR by Texas Instruments. It offers up to 95% efficiency in a small SOT23 package. It is able to handle a lot more current than the battery's maximum thus it would not overheat even without any heat sinks. The TLV also has internal overcurrent and overtemperature protections which offers redundant protection with the battery's protection circuit.

For battery charge controller a XC6803 series IC by TOREX is chosen. It works with an input voltage ranging from 4.5V to 6V, which makes it appropriate for USB charging. It supports configurable charging current from 40mA to 280mA and also has a capability to attach an NTC, which the chosen

battery has, for temperature control. This battery charger is contained in a small package, so it takes minimal PCB footprint and requires few external components to configure for the chosen battery.
The choice of the simplified battery circuitry does not offer battery state of charge monitoring which would be necessary for the final product of BullsAi. By using the bq25120A it is possible to wake up the device by touch, using capacitive sensors or using an interrupt from the accelerometer, but now an on/off slider is used. Since those features were not crucial for a prototype it was opted for to skip them in order to have a more robust design and to fit in a smaller PCB footprint.

**Electrical conclusion**

The electrical part of this project group was responsible for designing and making the hardware and software of the system. First, all sub-questions needed to be answered to come to a well thought design and sustainable design which would be ready for market as a minimal viable product. The biggest challenges were making it small enough for a wearable and making the systems sample- and sending frequency high enough for the AI to get a proper data set. At first, research was done to look for way of communicating with a smartphone without drawing to much energy. This led to BLE being a viable option. Later, was found out that not all smartphones can handle the fast data stream which leaded to a reduce in sending frequency. Secondly, the accelerometer had to have a high enough sample frequency. This one turned out fine with a sample frequency of 1KHz maximum. The accelerometer was also precise with 3 decimals behind the comma and with a range of +/- 2g.
A highly integrated battery management system and a power delivery solution was made at first. It was the clear best option as it was I2C programmable, so it required fewer external components to configure. The small number of external components also meant that the component PCB footprint would be minimized. Moreover, the initial battery system solution had the feature of estimating remaining battery percentage.
It was necessary to simplify the initial complicated circuit to maximize the change that the circuit works form the first time. This was since at the university's facility it was not possible to prototype circuits with small copper traces and miniature SMD components. Therefore, it was not possible to make multiple iterations of the PCB design in case of a failure. As a result, a new battery charging system was made with simple to use components. It was also necessary to put a separate buck converter since the previous option had it integrated. In this case the team was able to maximize the chances that the device would work from the first design iteration. In the end, design of the PCB was a lot of work, but in the end, it was possible to make it small enough to fit on a wrist, by using small options for components.

**Electrical recommendations**

First of all, looking at the BLE, it is recommended to lower the overall sample- and sending frequency. This would lead to a lower load on the BLE which will decrease the power usage of the whole system, it also leads to a broader usage of the system with phones with a les high BLE frequency. Another possible fix could be the use of BLE V4.2 with larger packet sizes. This would create less overhead per message, by sending more messages at once. On the other hand, this would create a delay in the data stream because every time, several samples have to be read, before filling the full 255 Byte.
Secondly, the initial solution for a battery charge controller and power deliver was clearly the best choice for this product. It was due to external circumstances that it was not put in the first prototype iteration. However, for the final product that is planned to be released for BullsAi it is highly recommended that the integrated battery system is used, as this will offer more features, offer higher efficiency, and allow to further miniaturize the PCB. In this way the mechanical team will have a bigger freedom to modify the design of the product. Finally, it would be possible to wake up the device in a more innovative way e.g., by capacitive touch sensor or by shaking, which will contribute to the futuristic nature of the device. The better design along with the more features and longer battery life will certainly increase the customers opinion of the product.

# 2. Mechanical

## 2.1 The Bracelet

In the system breakdown the mechanical part of the project consists of two parts, the casing, and the bracelet. The design of the bracelet contains the following sub questions:

- How can we mount the sensor tight around the wrist?
- How can we mount the sensor to a vertical, flat metal surface?
- Is it reasonable to develop and produce a bracelet + casing combination inhouse?
- How is the bracelet going to be connected to a flat metal surface?
- What is the best design for the case?
- What is the best production process for the casing?

## 2.2 How can the sensor be mounted tight around the wrist?

The sensor needs to be mounted to the wrist to be able to track upper body exercises. To prevent the accelerometer inside of the sensor picking up noise signal from moving, the fit around the wrist needs to be tight. To mount the sensor tight around the wrist some sort of strap attached to the casing is required. Looking at existing solutions, there are patented legal expired universal solutions available. From a business perspective choosing a universal available attachment solution, which is legal to use, is favourable since development is already done and production lines are running efficiently.
Watch band springs is the most available, legal expired, universal attachment method. Other companies, like apple, have their own attachment methods. But these designs are most of the time patented and there for not legal to use.

*Figure 8 Watch band spring*

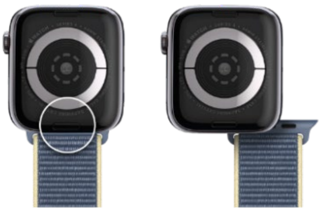


*Figure 9 Apple band attachment piece*

## 2.3 How can the sensor be attached to a vertical flat metal surface?

In some use-cases the acceleration of an exercise cannot be measured from a user's wrist. For example, a leg-extension machine or a hip-trust. In these scenarios it is needed to place the sensor directly on the weight being moved.
The sensor will be attached to a flat metal surface making use of magnets. The magnets will be imbedded in the strap, as shown below. The ribs in the wristband are magnets, pressed between a flexible plastic compound.

*Figure 10 Magnetic strap with classic watch band strips*

## 2.4 How is the bracelet going to be connected to a flat metal surface?

To attach the bracelet to a flat metal surface like gym equipment, magnetics will be used. The choice has been made to use straps with magnetic properties in order to reduce the volume of the casing. This will be further explained in a different sub question in this paper.

## 2.5 What is the best production process for the casing?

In order to decide which production process suits this product best, Design for Excellence has been used. By listing customer values, specifications and general requirements a clear view can be created what aspects are important when making a choice in the production process. The production processes that were compared are 3D printing, injection moulding and form pressing. These processes were compared by the following key aspects: sustainability, costs, quality, portability, reliability, manufacturing, reuse and maintainability. These aspects were scored according to whether they suit this case. The difference between the production processes were relatively small. As 3D printing gives more freedom in terms of the design, and 3D printing isn't as costly as the other production process 3D printing was chosen as the optimal available production process. PLA will be used as the printing material, as this is the most common and well-known material with good strength and tension.

## 2.6 What is the best design for the case?

The case should protect the hardware and should also close around the hardware as close as possible in order to improve the usability of the product. The casing will consist of a top and a bottom part which will tightly close the pcb board. Therefore, the pcb will have limited moving space. The top and bottom part will be packed together, and form closed by each other by the hooks that are sticking out at the top. An overview of the casing is shown in figure 11.

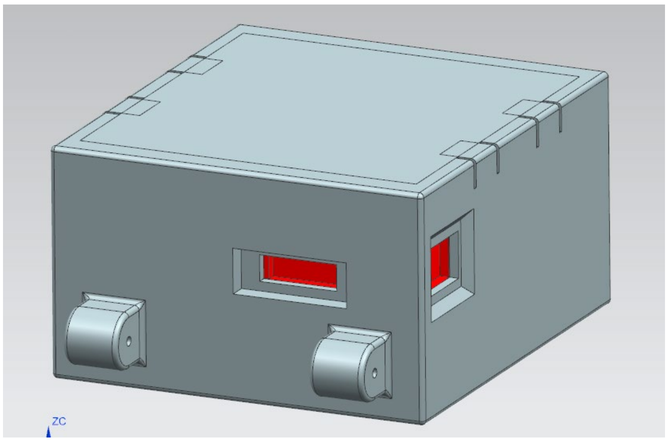


*Figure 11: Overview of the casing*

## 2.7 Mechanical conclusion

The choice has been made to place the magnets in the straps in order to keep the volume of the casing as low as possible. After using the Design for Excellence method, 3D printing was chosen to use as the preferred production process method. Therefore, the material that will be used for the casing will be PLA. The casing is designed to fit the electrical components as closely as possible. The straps will be bought as this will be the most efficient way to get straps with decent quality.

## 2.8 Mechanical recommendations

It is advised to buy the straps. The design of the connection of the straps to the casing is designed in such a way that when the connection should be adjusted, it can be easily done. It is therefore advised to look for straps that best suit the magnetic properties that the straps should have, and not the connection to the casing.
The casing can be made smaller by looking closer at the placement of the electronics. It is recommended to do so in order to improve the usability of the product.

## 3. Business

Producing and launching a start up with a product like BullsAi from a rough idea will only succeed with an extensive business plan. To get a clear overview of all the aspects that must to be taken into account the Lean Canvas is useful tool. The value proposition that BullsAi has is clearly explained by finding a solution for the problem people experience while training in the gym.

### 3.1 Crossing the chasm

How to sell disruptive products to mainstream customers? Start-ups often have a hard time transitioning selling their innovative product or service from the early market to the mainstream market. It is the difference in viewpoints between these two groups that is known as "the chasm".
To create a strategy for crossing the chasm it is important to understand the technology adoption lifecycle. In the technology adoption life cycle, you will find different types of customers, each with their own characteristics and demands.

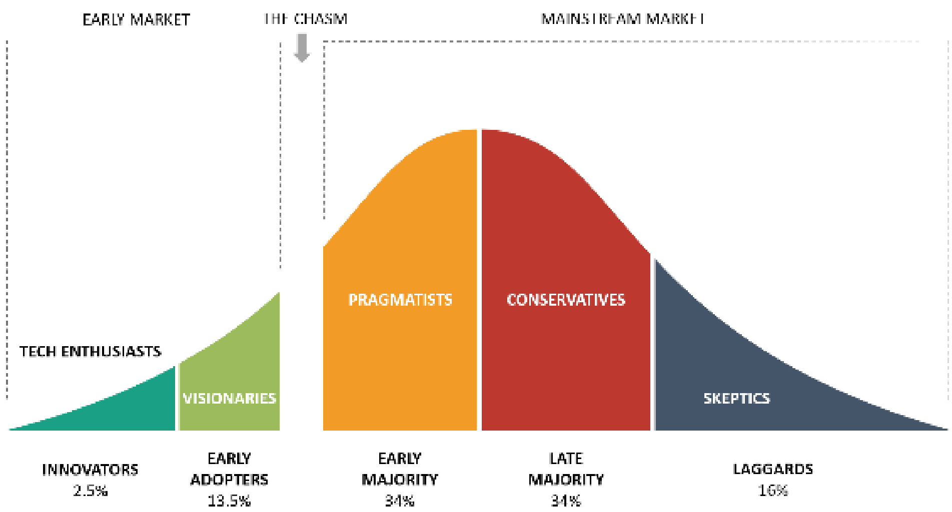



*Figure 12 Product lifecycle*

**Innovators:**

- Technology enthusiasts
- Care about the technology property's.
- Do not care about the market success.

**Early adopters:**

- Pioneers
- Align the technology with strategic opportunity.
- Are willing to take risk to achieve competitive advantage.

**Early majority:**

- Strong sense of practically
- Not willing to take risks.
- Seeks for reference.

**Late majority:**

- Will wait for a technology to be completely developed before adopting.

**Laggards:**

- Are not willing to adopt a technology, until it is a necessity.

To cross the chasm, we first need to find a group of induvial who absolutely need our solution to solve their problem. We can do this by targeting a very niche audience, driving all the competition out and use our customer relationship for future development. By finding a problem that is worth solving for this group we can scale our customer base purely on the solution we provide for their needs. we will return on this in chapter (Pivot).
Although the early market was happy to settle for a product to build on, the mainstream market expects the whole product. It is not easy to develop the whole product, therefore it is very important to create a customer base as early as possible to help you improving by using your product and providing feedback. The only way to find these customers, also called early evangelists, is by finding a problem the need you to solve.

### 3.2 Pivoting from target audience

In our first lean model canvas we targeted amateur trainees who go to the gym with the main purpose of muscle development. Our assumption was that this group was aware of an optimal between training to hard and training not hard enough, and that their biggest pain point was assessing reps in reserve.
We started out talking about the Concierge MVP (Manually providing the solution) of our product, in this case a personal trainer. A big part of their service is telling their customer when to stop an exercise and often push them a little harder, determining when to adjust weights and keeping track of their progress.
The important question in these conversations was “what could a personal trainer provide for you?”. None of the trainees we interviewed named in a tot 3 of their pain points “I have a hard time estimating reps in reserve”. Digging deeper most of them where not even aware of the mistake they are making. They just always train to their max.
Next up where ex clients of personal trainers who trained for muscle development. We targeted them because they have already paid for a solution and stopped for a reason. Again, same result.
Last we posted a question on the biggest Dutch training forum Forum Bodybuilding. This forum is owned by a stakeholder XXL nutrition, so our post just stayed up on the main page. We made a post with signal words, which contained words someone with the problem as we saw it would react to. In 2 weeks’, time, 160 reads, we got 1 reaction.
The conclusion we can make from this is that the current target audience is not emotional enough about the problem we assume they have. Once an individual creates awareness, the pain point itself will shrink. But the worst part is, most of this group does not realize they are not training optimal and that they are making mistakes. Also, looking at the market for this similar product, we see too much competition arising to doubt about a need in this market existing.
The pivot visioned is towards more emotional driven customers in the market. Beginners who are looking for a personal trainer. They are looking for guidance and a solution to their lack of knowledge. But this group will not look for a device which tells them how hard to train, since they do not know how to train properly at all.
Our assumption is that this target audience is looking for a cheaper alternative for a personal trainer, which provides reliable information and guidance during training. With this though process lean canvas 2 was created.

### 3.3 Conclusion Lean Canvas 2

The Lean Model Canvas is used to get a specific insight in what gym trainees need when they are training. The question that remains is ‘How to add value with BullsAi to user in the gym?’.
We believe that learning how to train optimal takes too much effort for an average gym trainee.
We can make this process easier with the current available AI technology and algorithms and by providing correct information about training fundaments.

We will achieve this by providing an efficient training course on training fundaments and learning users how to guide themselves with a sensor integrated in an user friendly app to support users with their biggest pain points in the gym.

## 4. Conclusion

The electrical team concluded that BLE is the best option to transfer data from the wearable device to a phone. There still are some doubts whether the BLE connection will be able to handle the required bandwidth for data transfer, however this can only be tested when the prototype is ready, and adjustments can be made based on that. An appropriate accelerometer for the devices was found. It offered the required accuracy and frequency of measurements. Research into different battery technologies concluded that using lithium-ion or lithium polymer batteries was the best option. Due to their dangers, it was necessary to pay extra attention into keeping them safe. Initially a highly integrated solution for managing the battery and power delivery was found, however due to external factors it was necessary to do the first prototype with a simplified circuit.

### Recommendations

To make sure that the BLE connection can handle the data transfer rate it is recommended to find a way to lower the amount of data that needs to be transferred or use a newer BLE standard that can handle the higher data bandwidths. This would also improve the battery life of the system.
The final products that get mass produced can make use of custom-made batteries, that would offer better capacity, while still fitting the designated space for batteries. The initial complex power management system has to be implemented in the final products, as it is more efficient, smaller and also offers more features.

## 5. References

[ „mathworks.com," mathworks, [Online]. Available: https://www.mathworks.com/help/comm/ug/modeling-of-ble-devices-with-heart-rate-profile.html. [Geopend 05 01 2021].

[ „learn.adafruit.com," adafruit, 06 11 2020. [Online]. Available: https://learn.adafruit.com/alltheiot-transports/bluetooth-btle. [Geopend 05 01 2021].

[ „Espressif.com," 10 2018. [Online]. Available: chrome-extension://oemmndcbldboiebfnladdacbdfmadadm/https://www.espressif.com/sites/default/files/documentation/ESP32_FAQs__EN.pdf. [Geopend 05 01 2021].

[ „LP-402025-1S-3 datasheet," 2 January 2012. [Online]. Available: http://www.farnell.com/datasheets/1666646.pdf. [Geopend 5 January 2021].

# Autonomous UV-C Disinfection Robot: Light Source

Enrique Mateo Medina[1], Stef Smits[2], Noud van Spall[3], Erik van de Wardt[4], Luc Willemsen[5]

1Fontys, Mechanical Engineering, Eindhoven
e.mateomedina@student.fontys.nl

2Fontys, Electrical Engineering, Eindhoven
stefsmits.smits@student.fontys.nl

3Fontys, Electrical Engineering, Eindhoven
n.vanspall@student.fontys.nl

4Fontys, Mechanical Engineering, Eindhoven
e.vandewardt@student.fontys.nl

5Fontys, Mechatronics, Eindhoven
luc.willemsen@student.fontys.nl

**Abstract:** Due to the recent COVID-19 pandemic, the interest for cheap and effective disinfection solutions has increased significantly. This calls for research into alternative ways of disinfecting. UV-C can be a potential solution to effective disinfection, is has already been proven to be suitable for this situation. This project investigates the feasibility of UV-C aided cleaning of a hotel room. To investigate this, a test plan is constructed which will verify the research done into UV-C and its capabilities.

**Keywords:** Disinfection, UV-C, Autonomous, Cleaning

## 1. Introduction

The recent COVID-19 pandemic has affected people across the world, this caused a change of the view on safety. Sterilization is becoming more relevant to all people and markets, causing the market for cheap, effective and safe disinfection solutions to grow significantly. Currently, the standard for disinfecting surfaces is using alcohol-based liquids, this can damage the surface and is in some cases not effective due to the human contact with the surface. A possible development in sterilization could use UV light to kill viral and bacterial particles. UV-C is known to be a possible solution to general disinfection, it has been widely used to sterilize air, sterilize water and disinfect smartphones. It can provide a more thorough disinfection while not damaging the surface, UV-C based disinfection systems can also kill organisms floating in the air. This paper describes the project that investigates the feasibility of UV-C aided cleaning of hotel rooms and its requirements. The client proposes to design an autonomous robot that disinfects surfaces present in the hotel room, in addition to the regular cleaning operations. This calls for an investigation on the safety and requirements of such a device. This project focusses on the UV-C light module and its power source.

## 2. Background

UV light consists of electromagnetic waves with a wavelength between 100 and 420 nanometres, within the UV light spectrum there are three distinctions: UV-A, UV-B and UV-C. UV-A ranges from 320 to 420 nanometres and makes up most of the UV light that reaches the earth's surface. UV-B ranges from 280 and 320 nanometres and causes skin burn, UV-B is largely absorbed by the atmosphere and thus makes up only 1,3% of the UV light on earth. UV-C ranges from 100 to 280 nanometres and is fully absorbed by the atmosphere, this form of UV light is able to kill bacteria, viruses and other organisms. (Stanford SOLAR Center, 2015) This form of UV light is very dangerous and can cause skin lesions within a very short time.

Hospitals have used UV-C to disinfect operating rooms for years and it has proven to be very effective, UV-C radiation can kill 99.9% of viruses within 15 minutes with a sufficient dose. (William A. Rutala, 2015) However, these devices radiate the whole room from a stationary point, this means that surfaces that are not directly radiated by the UV-C source need a longer exposure time to disinfect. To achieve sufficient disinfection within an acceptable amount of time objects must be placed in direct line of sight with the UV-C source. Thus, resulting in an even bigger challenge for hotel rooms or comparable applications. A solution to this could consist of an autonomously moving device with a UV-C source mounted to a moveable arm. This project researches the feasibility of such a system and the capabilities of UV-C in the context of disinfection.

## 3. Approach

In this project's current phase, the feasibility of a UV-C light source mounted on an autonomous moving robot's arm. The first step is to define the requirements for this module. For this, multiple parameters must be taken into consideration. The independent robot arm must carry and efficiently move the light source. Hence, the entire module has to be light and small enough for manoeuvrability to be as high as possible to rapidly sweep all the desired areas. Moreover, it must be energy efficient in terms of battery life, so with one charge, it can cover more than two rooms. The client expects the device must finish disinfecting a surface within a reasonable time, and the device must be safe for the operator.

## 4. Research

The most important research topic is safety, not only the safety of the finished product must be taken into consideration but also the safety during the testing phase. Exposure to UV radiation can be hazardous, even if it a short period of time, damage is subject to exposure time, the intensity of radiation, wavelength, and the individual's sensitivity to UV light (Newport, n.d.). The generation of UV-c generates a non-negligible amount of ozone.

| Permissible UVC Exposures | |
|---|---|
| Duration of exposure per day | Irradiance ( $\mu W/cm^2$) |
| 8 hours | 0.2 |
| 4 hours | 0.4 |
| 2 hours | 0.8 |
| 1 hour | 1.7 |
| 30 minutes | 3.3 |
| 15 minutes | 6.6 |
| 10 minutes | 10 |
| 5 minutes | 20 |
| 1 minute | 100 |

*Figure 20: Permissible UVC Exposures according to ACGIH*

Figure 1 displays the relation between intensity and times of exposure, established by ACGIH (American Congress of Governmental and Industrial Hygienist) these times and/or intensity if exceeded they will be harmful. (2 )

**The Skin:**
UV-B and UV-C causes erythema (sunburn) and skin pigmentation (tanning). If there is a long-term exposure can result in premature aging, which is loss of skin elasticity. Moreover, there is a documented connection between wavelengths that are lower than 320nm and basal cell and squamous cell carcinoma, in other words skin cancer. But several studies are raising concerns over possible wavelength that carcinogenesis peaks at 290nm.

**The eyes:**
The absorption of UV-C and B light can cause conjunctivitis and photo keratitis which is corneal inflammation even though it does not penetrate the eye lens. If the eyes are over exposed the subject will develop cataracts, but this mainly is caused from UV-a overexposure, if the wavelength is longer than the UV-a may cause 'blue blindness' which is a type of colour blindness.
It is clear that users should avoid exposure at all cost, fortunately this is fairly simple, since the UVC is mostly absorbed by most objects in the surroundings, at the same time standard glass absorbs most of rays. Moreover UV-c is also absorbed by dead skin.

**Safety precautions:**
Since it is required to use UV light there are certain guidelines that must be strictly followed in order to avoid and or reduce hazards. In reality to avoid the hazards, the best way using UV light source, but since the team was asked to use this type of guidelines, the team will follow the guidelines.

- Limit access to areas where UV sources are used
- Post warning signs at the entrance of the working areas where UV will be utilised
- Wear protective eyewear and gloves that meet safety standards
- Cover arms and neck and limit exposure time
- Never look directly at the light source
- Use a manual or electronic shutter to close the beam when the source is not in use
- Use enclosed beam paths if possible

The last two are not applicable in our case as for now, but good to take into consideration.

**Protective Gear:**
Since the team will be conducting experiments on how efficient the light is, they must acquire PPE (personal protective equipment) (Wayne State University).
In terms of clothing, a standard laboratory apparel fully buttoned lab coat, long pants and closed shoes. When operating the light source, it is important to be vigilant to prevent gaps in the clothing, especially in zones like the neck and wrists. When it comes to gloves the recommended ones are latex or nitrile gloves, or even soldering gloves (Anne von Koschembahr, 2017).
Eye/face protection, if there is any potential exposure to UV, a polycarbonate face shield stamped with the ANSI Z87.1-1989 UV certification must be worn in order to protect the face and eyes. Moreover, certified UV glasses will protect the eyes, but the face may suffer burns in the area that does not cover the eyes. If no face shield is available sunscreen can be utilised according to Dr.Anne von Koscshembahr, from the Atomic Energy and Alternative Energies Commission. (Anne von Koschembahr, 2017)
Moreover, according to Dr.Didier Gillotay, from the Royal Belgian Institute of Space Aeronomy (Anne von Koschembahr, 2017). It is possible to materialize the UV beam with acetyl salicylic acid pills, this generates a fluorescence when irradiated by UV at a length of 254nm. He also recommends using an ozone extractor, because when UV-c is generated a non-negligible amount of ozone is produced.

These are the personal measures that must be followed, but the team will also implement safety measures to the system in other to make things safer. Some of these system features are taken from the products already available to us.

- Being able to control the irradiance at different distance
- Autonomous mobile disinfection to reduce operator exposure
- Optimization of the killing path, this should be planned beforehand
- The process is safe and controllable, try to implement a sound system to remind people and infrared system that shuts down the machine when accidental presence is detected

There are different types of unwanted micro-organisms, or germs, that UVC lights can help get rid of. Common types are bacteria, moulds, yeasts and viruses which are of course an important subject in present times. These micro-organisms all react differently to germicidal action by UVC lights, so this needs to be taken into account while testing.
The required dose to kill 99% of germs can be approximated with the following equation:

$$\frac{4.6}{k} = It \qquad \text{(1) (Philips Electronics N.V., 2006)}$$

Where:
**I** Is the intensity of UV-C light
**k** is a constant rate depending on the species
**t** is the time required to kill 99% of species

The required dose to kill 90% of micro-organisms and the k rate for different types of germs is given in the table in Figure 2.

| UV dose to obtain 90% killing rate | | |
|---|---|---|
| **Bacteria** | **Dose** | **k** |
| Bacillus anthracis | 45.2 | 0.051 |
| B. megatherium sp. (spores) | 27.3 | 0.084 |
| B. megatherium sp. (veg.) | 13.0 | 0.178 |
| B. parathyphosus | 32.0 | 0.072 |
| B. suptilis | 71.0 | 0.032 |
| B. suptilis spores | 120.0 | 0.019 |
| Campylobacter jejuni | 11.0 | 0.209 |
| Clostridium tetani | 120.0 | 0.019 |
| Corynebacterium diphteriae | 33.7 | 0.069 |
| Dysentery bacilli | 22.0 | 0.105 |
| Eberthella typhosa | 21.4 | 0.108 |
| Escherichia coli | 30.0 | 0.077 |
| Klebsiella terrifani | 26.0 | 0.089 |
| Legionella pneumophila | 9.0 | 0.256 |
| Micrococcus candidus | 60.5 | 0.038 |
| Micrococcus sphaeroides | 100.0 | 0.023 |
| Mycobacterium tuberculosis | 60.0 | 0.038 |
| Neisseria catarrhalis | 44.0 | 0.053 |
| Phytomonas tumefaciens | 44.0 | 0.053 |
| Pseudomonas aeruginosa | 55.0 | 0.042 |
| Pseudomonas fluorescens | 35.0 | 0.065 |
| Proteus vulgaris | 26.4 | 0.086 |
| Salmonella enteritidis | 40.0 | 0.058 |
| Salmonella paratyphi | 32.0 | 0.072 |
| Salmonella typhimurium | 80.0 | 0.029 |
| Sarcina lutea | 197.0 | 0.012 |
| Seratia marcescens | 24.2 | 0.095 |
| Shigella paradysenteriae | 16.3 | 0.141 |
| Shigella sonnei | 30.0 | 0.077 |
| Spirillum rubrum | 44.0 | 0.053 |
| Staphylococcus albus | 18.4 | 0.126 |
| Staphylococcus aureus | 26.0 | 0.086 |
| Streptococcus faecalis | 44.0 | 0.052 |
| Streptococcus hemoluticus | 21.6 | 0.106 |
| Streptococcus lactus | 61.5 | 0.037 |
| Streptococcus viridans | 20.0 | 0.115 |
| Sentertidis | 40.0 | 0.057 |
| Vibrio chlolerae (V.comma) | 35.0 | 0.066 |
| Yersinia enterocolitica | 11.0 | 0.209 |

| UV dose to obtain 90% killing rate | | |
|---|---|---|
| **Yeasts** | **Dose** | **k** |
| Bakers' yeast | 39 | 0.060 |
| Brewers' yeast | 33 | 0.070 |
| Common yeast cake | 60 | 0.038 |
| Saccharomyces cerevisiae | 60 | 0.038 |
| Saccharomyces ellipsoideus | 60 | 0.038 |
| Saccharomyces sp. | 80 | 0.029 |
| **Mould spores** | | |
| Aspergillus flavus | 600 | 0.003 |
| Aspergillus glaucus | 440 | 0.004 |
| Aspergillus niger | 1320 | 0.0014 |
| Mucor racemosus A | 170 | 0.013 |
| Mucor racemosus B | 170 | 0.013 |
| Oospora lactis | 50 | 0.046 |
| Penicillium digitatum | 440 | 0.004 |
| Penicillium expansum | 130 | 0.018 |
| Penicillium roqueforti | 130 | 0.018 |
| Rhizopus nigricans | 1110 | 0.002 |
| **Virus** | | |
| Hepatitis A | 73 | 0.032 |
| Influenza virus | 36 | 0.064 |
| MS-2 Coliphase | 186 | 0.012 |
| Polio virus | 58 | 0.040 |
| Rotavirus | 81 | 0.028 |
| **Protozoa** | | |
| Cryptosporidium parvum | 25 | 0.092 |
| Giardia lamblia | 11 | 0.209 |
| **Algae** | | |
| Blue Green | 3000 | 0.0008 |
| Chlorella vulgaris | 120 | 0.019 |

*Figure 21 - UV dose per organism (Philips Electronics N.V., 2006)*

**UV-C lighting options:**
Generating the UV-C spectrum can be achieved in different ways. Most common is the low-pressure mercury lamp, which look like regular TL-lights and are available in a variety of lengths. Next, there are the Xenon pulse and LED UVC lights. At the moment LED UVC lights are undergoing big steps in development. So, for this project, which solution fits best and why? Therefore, all three options will contain some basic information.
**Low-pressure mercury:**
A normal mercury discharge lamp uses an electric arc through vaporized mercury. This is done in the inner tube, by varying the pressure of the vaporized mercury, the emitted wavelength can be changed. Lower pressure will emit shorter wavelengths, thus radiating UVC (focused at 253,7 nm), when doing so, efficiencies can go up to 35%. As an extra safety feature, most LP-mercury lamps are covered in fused silica to prevent the production of (too much) Ozone, which happens with wavelengths around 180nm.
**Xenon pulsed:**
As it is in the name, xenon solutions emit UVC light in a pulsed manor. This pulse lasts a few milliseconds and has a much higher amount of UVC radiation in those milliseconds. While emitting higher amounts of energy, due to the short time, the eventual dose would stay the same as a comparable LP-mercury lamp. The main advantage of this, would be the ability to penetrate deeper into fabric or liquids. Nonetheless, several studies, concluded that despite using higher numbers regarding power, time to clean a room/objects stays the same regarding LP mercury lamps. Next to that, these units are relatively expensive and tend to be rather large.
**LED UVC:**
LED UVC modules are really in development lately. They are compact and emit a narrow wavelength centred around 278 nm. Next to these advantages, they do not need high voltages to work properly, which could benefit the UVC project. However, there is one main disadvantage, and that is the emitted power; To give a simple calculated example:

***Osram HNS L18W:***

$$P_{in} = 18\,Watt$$

$$P_{radiated} = 5{,}5\,Watt$$

$$Efficiency = \frac{5{,}5}{100} * 100 = 30{,}5\%$$

***XST-3535-UV:***

$$P_{in\_max} = 0{,}8A * 5 = 4\,Watt$$

$$P_{radiated} = 0{,}1\,Watt$$

$$Efficiency = \frac{0{,}1}{4} * 100 = 2{,}5\%$$

$:Needed\ amount\ of\ LED's = \frac{5{,}5}{0{,}1} = 55$

*Calculation 1: Comparison example, LP-mercury VS. LED*

As seen in this example an array of 55 high-power LED's is needed to match the output of one LP-mercury lamp. With these large amounts of LED's, new challenges arrise such as placement and higher power demands. Still, UVC LED's are in the uprise, and can be a suitable replacement in the (near) future.

**Comparison table:**

| | Efficiency: | Max radiated power: | Size: | Power demands: | Cost: | Safety: | Total: |
|---|---|---|---|---|---|---|---|
| LP mercury UVC | 7 | 7 | 8 | 6 | 10 | 6 | 44 |
| LED UVC | 6 | 2 | 8 | 8 | 6 | 8 | 38 |
| Xenon Pulsed UVC | 9 | 10 | 3 | 3 | 2 | 3 | 30 |

*Table 1: Comparison table of different UV-C emitting solutions.*

**Conclusion:**
When examining the information above, LP mercury lamps look like the most viable option. They are cheap, compact and emit enough UVC for our project. Main current disadvantage would be the operating voltage while using batteries. LED UVC would be the next viable option. Mainly because of the compactness and the high efficiency. Unfortunately, current power handling of LED's makes them not powerful enough. At last, there is the xenon pulse solution, while probably being a solution for larger UVC cleaning devices, the size immediately was a problem for the UVC cleaning robot. Therefore LP-mercury would be the best solution. With this in mind, a selection was made with some suitable products (the ones in bold are being tested).

| | Power (W) | Radiated Power (W) | Nominal Voltage (V) | Size (mm) | Base: | Cost (estimate in euros) |
|---|---|---|---|---|---|---|
| **Type:** | | | | | | |
| **Osram HNS L 18 W 2G11*** | 18 | 5,5 | 58 | 214x40 | 2G11 | 13,- |
| Osram HNS L 24 W 2G11 | 24 | 7,3 | 87 | 314x40 | 2G11 | 15,- |
| Osram HNS S/E 11 W 2G7 | 11 | 3,6 | 75 | 212x28 | 2G7 | 8,- |
| Osram HNS S/E 9 W 2G7 | 8 | 2,5 | 48 | 142x28 | 2G7 | 8,- |
| Philips TUV PL-L 24W/4P UNP/50 | 24 | 7,1 | 87 | 320x39 | 2G11 | 17,- |
| **Philips TUV PL-L 18W/4P 1CT/25*** | 18 | 5,5 | 60 | 225x39 | 2G11 | 13,- |
| Philips TUV PL-S 13W/2P 1CT/6X10BOX | 11 | 3,2 | 89 | 178x28 | GX23 | 13,- |

*Table 2: Selection UV-C LP-mercury lights.*

## 5. Test plan

The goal of the project is to eventually be able to disinfect certain objects that are commonly present in hotel rooms and are often touched by visitors, such as a remote, the coffee maker and of course doorknobs. Therefore, the test phase will consist of the disinfection of such an object using the UVC light source that seems most suitable for the job.
During testing several aspects will have to be tested:

- Does the light emit UVC light in the first place?
- Is the UVC module able to radiate UVC light for the required amount of time?
- Does a change in distance have the expected effect on the received dose?
- What dose is needed to kill 99% of the unwanted infectants?
- What exposure time is needed to meet 99% disinfection?

Important for good disinfection of solid surfaces is that all of the surface is radiated to reach a sufficient dose to kill germs. This means the light has to directly radiate or radiate via reflective surfaces such as aluminium shells. Aluminium is a great choice for reflecting UV-C radiation because it reflects up to 70% of the emitted radiation (Philips Electronics N.V., 2006), this means the efficiency of one light source can be improved by adding a reflector above the light source.

A suitable method for testing the UVC light is by picking an object that is often used in hotel rooms, for instance a remote, a door knob or even a touchscreen, and expose half of the contaminated surface to UVC radiation. This way the exposed surface can be compared to the non-exposed surface.
Further details on the test plan and different distance and dose testing are to follow.

**Validating the effect of the UVC radiation**
In order to validate the working of the chosen UVC lamps testing will have to be done. Two different tests will be done, the first test will test the rate of disinfection at different exposure doses, and the second test will test the disinfection rate at different distances from the lamps. The results will be obtained by taking samples of the surfaces before and after exposing them to UVC light. These samples will each get an agar plate in which any present bacteria will grow. The growing of these colonies will be done with the help of the study Fontys Technical Natural Sciences.

**Test 1**

Description: Have 3 phones cleaned first and then contaminate them (let everyone touch it, lay it down on the floor). 1 phone will be radiated with the calculated dose to kill 99% of germs, 1 with double the dose and 1 with half.
Steps:

- Clean the touchscreen of all 3 phones with disinfectant
- Take a sample of the cleaned touchscreens with swabs and rub them in three different agar plates (mark them)
- Contaminate the touchscreens by touching them, putting them on the floor and breathing on them
- Place the first phone at 20cm from the light
- Expose the phone to the calculated dose to kill 99% of all germs
- Take a sample of the touchscreen with a swab once the UVC light is turned off and rub it in an agar plate (mark it)
- Repeat for phone 2 with 200% of the dose and for phone 3 with 50% of the dose
- Let the agar plates develop

**Test 2**

Description: All phones get cleaned again and put at different distances from the light 10cm, 30cm and 100cm. The 3 phones will be radiated at the same time.

Steps:

- Clean the touchscreen all 3 phones with disinfectant
- Take a sample of all 3 cleaned touchscreens with a swab and rub each swab in different agar plates (mark them)
- Contaminate the touchscreens by touching them, putting them on the floor and breathing on them
- Place the three phones at 10, 30 and 100cm from the light
- Expose the phones to the calculated dose to kill 99% of all germs
- Take a sample of every touchscreen with a swab and rub the swabs in three different agar plates (mark them)
- Let the agar plates develop

## 6. References

Anne von Koschembahr, H. A. (2017). *What safety equipment should I prepare for the experiment using 254nm-wavelength UV lamp?* Von https://www.researchgate.net/ abgerufen

Newport. (n.d.). *Ultraviolet Safety Considerations*. Retrieved September 2020, from https://www.newport.com/n/ultraviolet-safety-considerations

Philips Electronics N.V. (2006). *Ultraviolet purification application information.* Roosendaal: Philips.

Stanford SOLAR Center. (2015). *UV Light*. Retrieved from http://solar-center.stanford.edu/about/uvlight.html

*Surface ATP test*. (2017). Retrieved from Hygiena.com: https://www.hygiena.com/hospitality-products/ultrasnap-hospitality.html

Tseng, C.-C., & Li, C.-S. (2007). Inactivation of Viruses on Surfaces by Ultraviolet Germicidal Irradiation. *Journal of Occupational and Environmental Hygiene, 4*(6), 400-405.

Wayne State University. (n.d.). *Ultraviolet Radiation Safety Fact Sheet.* Retrieved September 2020, from https://research.wayne.edu/oehs/pdf/factsheet-uv.pdf

William A. Rutala, M. F. (2015). *Room Decontamination with UV Radiation.* Cambridge: Cambridge University Press.